A DECISION TOOL TO OPTIMALLY SELECT
POLLUTION PREVENTION PROJECTS
WITHIN A CONSTRAINED BUDGET

THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering and Environmental Management
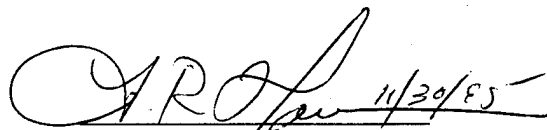
Charlotte Hudson, GS-11

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A DECISION TOOL TO OPTIMALLY SELECT
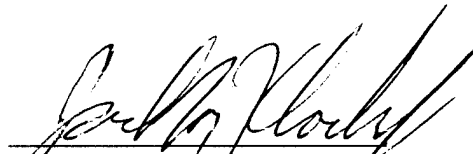## POLLUTION PREVENTION PROJECTS
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Dr. Tom Hauser

_____

LtCol Steve Lofgren

_____

LtCol Jack Kloeber

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LIST OF ACRONYMS

AF .... Air Force

AFB.. Air Force Base

AFI..Air Force Instruction

CERCLA....... Comprehensive Environmental Response, Compensation, and Liability Act

DPL ....Decision Programming Language

EPA ....Environmental Protection Agency

HSC..Human Systems Center

MEK...Methyl Ethyl Ketone

MIPS .... Material Input Per Service

NPV... Net Present Value

OA.. Opportunity Assessment

ODC .... Ozone Depleting Chemical

US .... United States

ABSTRACT

The recent trends of expanding global environmental awareness and a shrinking defense budget challenge Air Force pollution prevention managers faced with the task of solving environmental problems with limited resources. Pollution prevention managers need to select the best environmental projects for an installation within a constrained budget but have no standard way of selecting the optimal mix of projects.

This thesis proposes a decision tool to aid decision makers in choosing this optimal mix. The model was built using decision analysis theory which provides a framework to aid the decision maker. Criteria used in the model for selection was determined using a questionnaire sent to base-level pollution prevention managers.

The model uses DPL™, a software package designed to build, analyze, and conduct sensitivity analysis of decision problems to perform the quantitative analysis. Built in functions of DPL™ allow the decision maker to see the optimal decision policy based on the values entered into the model and to run sensitivity analysis to determine which values are the most critical to the outcome of the model. Decision analysis can be used to create a dominance curve that shows all optimal strategies based on the willingness of the decision maker to make tradeoffs between attributes. This model provides analytical data that can be used to justify decisions made by the pollution prevention manager when selecting the optimal mix of pollution prevention projects for implementation.

A DECISION TOOL TO OPTIMALLY SELECT POLLUTION PREVENTION PROJECTS WITHIN A CONSTRAINED BUDGET

I. INTRODUCTION

The recent trends of expanding global environmental awareness and a shrinking defense budget challenge Air Force pollution prevention managers faced with the task of solving environmental problems with limited resources. Pollution prevention safeguards the environment and also saves millions of dollars in treatment, compliance and acquisition costs (13:34). Pollution prevention managers need to select the best environmental projects for an installation within a constrained budget. There is currently no standard way of selecting the optimal mix of projects. The goal of this research is to develop a standard process for selecting an optimum set of products within given budget limitations.

Background

"The Air Force (AF) is committed to environmental leadership and preventing pollution by reducing use of hazardous materials and releases of pollutants into the environment to as near zero as feasible"(9:1-1). This policy was the result of the Pollution Prevention Act of 1990 in which Congress recognized that millions of US dollars were spent each year in trying to cleanup industrial pollutants released into the environment. The Act acknowledged there were significant opportunities for industry to

reduce or prevent pollution at the source rather than through end-of-pipe treatment. In response to The Pollution Prevention Act of 1990, the Air Force formalized a Pollution Prevention Program. As part of the Pollution Prevention Management Program, all installations were instructed to "conduct opportunity assessments (OA) on a recurring basis" (7:4).

An opportunity assessment, a major component of an effective installation-wide Pollution Prevention Program (see Figure 1-1), is a systematic analysis of current shop activities and operations. The purpose of the OA is to determine the amount of material disposed of as waste, provide a summary of hazardous materials usage and waste production, target processes and operations appropriate for pollution prevention activities, and establish a list of proposed alternatives for waste generating activities found in the assessment (30:5). The assessment process has four major components:

    1) Planning and Organization

    2) Assessment

    3) Feasibility Analysis and Selection of Solutions

    4) Implementation (15:1)

Planning and Organization

The first stage in the OA is the most critical. Without upper management support, an OA can not be successful. Upper management should establish goals and plans to achieve these goals. Established goals will help to focus the OA process and gain consensus among the employees of the organization (14:12-26).

POLLUTION PREVENTION OPPORTUNITY ASSESSMENT PROCESS

The recognized need to minimize waste

↓

PLANNING AND ORGANIZATION
Get management commitment
Set overall assessment program goals
Organize assessment program task force

Assessment organization and commitment to proceed

↓

ASSESSMENT PHASE
Collect process and facility data
Prioritize and select assessment target
Select people for the assessment teams
Review data and inspect site
Generate options
Screen and select options for further study

Select new assessment targets and reevaluate previous options

Assessment report of selected options

↓

FEASIBILITY ANALYSIS PHASE
Technical evaluation
Economic evaluation
Select options for implementation
Review data and inspect site

Final report including recommended options

↓

IMPLEMENTATION
Justify projects and obtain funding
Installation (equipment)
Implementation (procedure)
Evaluate performance

Repeat the process

↓

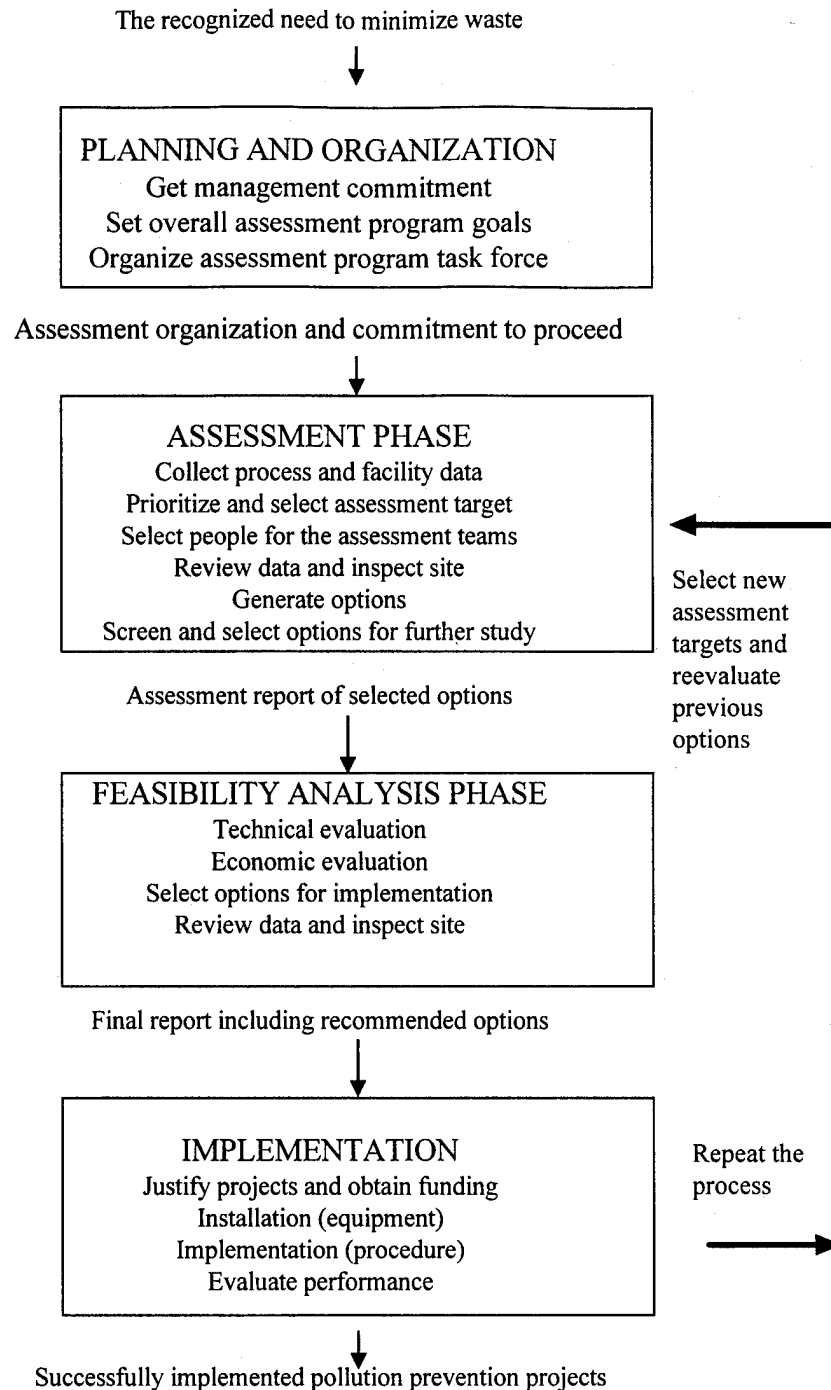Successfully implemented pollution prevention projects

Figure 1-1. Pollution Prevention Opportunity Assessment Process

(15:1)

3

Assessment

The purpose of the assessment phase is to first identify the waste generating processes which occur on the site. Once the processes are identified, the various waste streams are organized both qualitatively and quantitatively as to their toxicity and volume. This is done by means of surveys, inventory documents, operations logs, sampling and analyses. This organization allows data flow and material process diagrams to be developed. These process diagrams provide a pictorial method for identifying the origins and causes of waste generation.

Once the source and volume of waste generation are understood, the assessment enters the creative phase of generating a comprehensive set of pollution prevention options. It is possible that multiple options will be uncovered as a result of initial investigations. Options range from changing processes to buying new equipment to instituting new management practices. Alternatives for correction or improvement are generated by brainstorming for new ideas and adapting pollution prevention solutions that have worked in similar processes at other installations (14:27-34).

Feasibility Analysis and Selecting Solutions

When determining the appropriateness of a pollution prevention option, various factors must be considered. The three primary objectives of this phase include: 1) technical evaluation; 2) economic evaluation; and 3) selecting options for implementation (21:702). Technical evaluation refers to how well the option prevents pollution, how it works and if it

will even work. The economical evaluation addresses the cost benefits of the option (14:35-40).

Implementation

To implement a pollution prevention project a manager must first justify that the installation needs the project by demonstrating how the base will benefit from the acquisition and then seek or program for sufficient resources. The manager must ensure that proper equipment is available for the new project and that there are individuals trained in operating any new equipment. All aspects of how the project will be used must be examined during the implementation phase (14:40-42).

The Problem

The completed pollution prevention opportunity assessment suggests pollution prevention opportunities for a particular base. The pollution prevention manager must then select the most beneficial projects to implement often with little guidance and limited resources. There is currently no Air Force standard for selecting which recommended projects should be implemented in order to obtain the best environmental benefits for the dollars spent on capital costs.

Objectives

The objective of this thesis is to develop a model, and thereby a standard method, that will assist in selecting the optimal mix of projects to be implemented within a given budget.

To develop a decision tool to select the best mix of pollution prevention projects within a constrained budget, the following research objectives were established:

1) Identify the current methods for selecting pollution prevention projects.

2) Identify the criteria considered when selecting projects

3) Develop a decision model to select the best mix of projects using the criteria identified in Objective 2.

4) Test and evaluate the model in a case study using notional data.

Scope and Limitations

This decision tool will be designed for use by the installation pollution prevention manager when selecting projects to implement. The results of the model will be used to support justification to the installation Environmental Protection Committee for project implementation. In order for this decision tool to be a valuable model, correct and reliable data must be known for input. This model was built with the assumption that the Opportunity Assessment is performed by a contractor. Use of the model is limited to selecting among projects that an opportunity assessment has recommended with data supplied by the contractor.

II. LITERATURE REVIEW

Overview

Section one of this chapter will review the literature on the evolution of pollution

prevention, the Pollution Prevention Act, and benefits derived from implementing

pollution prevention. Selecting pollution prevention projects is a difficult task, partially

due to the uncertainties involved with the benefits derived from the implementation.

Often the requirements for projects exceed budget constraints. Selecting pollution

prevention projects is a multicriteria decision problem since the decision must be based

on economic and environment benefits. Section two of this chapter will review

multicriteria decision making and concepts associated with this process. The final section

of this chapter will discuss the concepts of decision analysis, a method often used to solve

hard, complex, and important problems.

Pollution Prevention

Background

In the past 30 years many laws were passed with the intent to preserve and

enhance the environment. These laws typically addressed end-of-pipe treatment solutions

to protect natural resources. Only in recent years has it been recognized that the best way

to protect our environment is to reduce the pollution at the source. Not only does this

method safeguard our environment, but pollution prevention also saves millions of dollars in treatment, compliance, and acquisition costs (13:34).

Technology has improved tremendously over past decades and with it the growing recognition of complex ecological realities that human activities have inflicted on our natural resources (13:10). Rachel Carson's publication of *Silent Spring* in 1962 brought to the world's attention the implications of pesticides and ecological issues and human health (4). This was one of the first landmark episodes which illustrated the effects of human activities on the environment. Love Canal in 1980 was another monumental episode where a residential area was built on top of an abandoned chemical waste dump causing health problems to those in the vicinity (23:6). This incident was instrumental in the passing of the Comprehensive Environmental Response, Compensation, and Liability Act. This Act provided a "superfund" for the cleanup of America's environmental disasters (23:5). Billions of dollars have since been spent on remediating America's past mistakes. The growing recognition that the Unites States annually produces millions of tons of pollution and spends tens of billions of dollars per year controlling this pollution and cleaning it up led to Congress passing the Pollution Prevention Act in October of 1990 (33:584).

Pollution Prevention Act

Congress passed the Pollution Prevention Act to emphasize the significant opportunities that exist for industry to reduce or prevent pollution at the source through cost-effective changes in production, operation, and raw materials use (33:584). The

need for change was realized because existing regulations did not give sufficient credit to reducing pollution at the source. Regulations have historically been geared toward end-of-pipe treatment and disposal (33:584). The Act stated the new policy for environmental considerations:

> The Congress hereby declares it to be the national policy of the United States that pollution prevention should be **prevented or reduced** at the source whenever feasible; pollution that cannot be prevented should be **recycled** in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be **treated** in an environmentally safe manner whenever feasible; and **disposal** or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner (33:584).

This new policy for environmental considerations is known as the pollution prevention hierarchy and is the recommended strategy for dealing with pollution.

Also required by the act was the creation of an office in the Environmental Protection Agency (EPA) to carry out the functions of the act (33:585). The purpose of this office is to promote a multi-media approach to source reduction and develop strategies in which to do so. A clearinghouse was also mandated by this law to provide industry and federal facilities with pollution prevention information.

A major implication of the act was the requirement for all industries to report pollution prevention efforts annually. This report contains the percentage reduction from the previous year in the quantity of toxic chemicals entering waste streams (33:588). Methods for reducing this pollution, either through source reduction or recycling, must be documented. The requirement for this report led to the need for pollution prevention assessments. Detailed information is required for these reports and a method is needed

for collection of the data. It became necessary for industry to conduct baseline surveys, ensure that pollution prevention progress could be tracked, and document all pollution prevention activities (26:40). Pollution prevention opportunity assessments were discussed in detail in Chapter One.

Pollution Prevention Benefits

In order to abide by the policy stated in the Pollution Prevention Act, installations need to reduce the use of hazardous materials, reduce waste streams, reuse and recycle wastes that can not be avoided and promote affirmative procurement. The cost of complying with environmental regulations is drastically increasing. Pollution prevention activities are a means of avoiding these costs as well as a means of preserving and enhancing the environment. Pollution prevention can reduce disposal costs for hazardous waste which have risen from $600/ton to $6500/ton since 1988, eliminate fines for mishandling wastes which can be up to $25,000/day/fine, and preserve limited landfill space (27:31).

The Naval Air Warfare Center Point Mugu, California instituted a waste stream management program that resulted in a total savings/cost avoidance of $2,400,000.00 for FY92 (22). The program reduced the quantity of hazardous materials on hand throughout the complex, minimized waste generated, and maximized recycling on the installation (22). This management program has now been implemented on Air Force Installations as the Hazardous Material Pharmacy. The Pharmacy concept reduced hazardous material

purchases at Hill AFB Ogden, Utah, by 50% and reduced hazardous waste generation at Luke AFB Phoenix, Arizona, by 74% in the first year of operation (27:45).

Many pollution prevention success stories have been well documented. To cover these in detail is beyond the scope of this paper. The intent here is to illustrate an example of the need, purpose, and usefulness of pollution prevention. An excellent source of information for pollution prevention, including a list of reference material, is the Facility Pollution Prevention Guide distributed by the EPA (14).

Air Force Methods for Pollution Prevention Project Selection

Research of current methods used by base-level pollution prevention managers indicated that there is currently no standard method for selecting projects (see Appendix A). Economics is a major consideration but by far not the only criterion used. Volume of hazardous waste reduced was another top factor of consideration along with harmful effects and safety.

Currently Air Force guidance suggests installations use the payback period method when selecting projects to implement (9:2.2.4). As part of the data gathering for this research a questionnaire was sent to base-level pollution prevention managers. The majority of the managers that replied to the questionnaire stated that they did not like using the payback period due to disadvantages of the method (See Appendix A). The two crucial theoretical errors of the payback period are:

1. The conventional method ignores the time value of money.

2. Does not consider the complete life of a project (17:170).

These shortcomings do not allow for consideration of pollution prevention projects that do not have a payback period but might be extremely beneficial to the environment.

One source suggests that the optimal economic strategy to use would be Net Present Value when selecting pollution prevention projects. The EPA's "A Primer for Financial Analysis for Pollution Prevention Projects" is a step by step instruction for preparing financial analyses for pollution prevention project justification. The primer states that since benefits from pollution prevention projects generally extend far into the future, discounting over long periods tend to mask the payoff value. Projects that have great benefit for the environment, but fail to have a short payback period are not selected if selection is based on payback period (12).

Pollution prevention managers also indicated that financial costs should not be the only costs considered when selecting pollution prevention projects (see Appendix A). Typically when assessing the cost benefits of eliminating or reducing a waste stream, decrease of disposal costs is the only cost addressed in the economic analysis. There are many other cost factors that should be considered when assessing the total cost of an environmental waste. These costs include, but are not limited to, long term liability costs, remediation costs, and even items such as personal protective gear associated with handling the waste. There has been limited research completed and models developed on what a waste actually costs to the user and how best to determine this cost.

One such model is the Material Input Per Service unit (MIPS) which is a way of accounting for the impact humans have on resources. The model, developed at the

Wuppertal Institute for Climate, Environmental, and Energy, gives a first approximation of the actual environmental costs of any particular product or action, from its creation to its dissolution (34:14-15). Although not an economic model *per se*, the model does look at all facets to determine cost to the environment. For instance, according to MIPS, one liter of orange juice requires twenty-two liters of water, four-tenths of a liter of fuel, and one square meter of land. Taken together, those represent 25 kilograms of material input for each kilogram of orange juice (34:14-15). It is this sort of detail that must be assessed when trying to place dollar figures with end products to determine total costs of associated wastes. Not only must the cost of disposal be examined, but all costs of associated waste that accompany the end product during its life cycle.

One aspect of trying to associate a dollar figure with long term environmental costs has been to create a model that estimates the liability costs using expected value analysis developed from microeconomic theories (2). This model, created by Dr. Jim Aldrich, can be used to justify investment for pollution prevention projects by forecasting potential cost savings. Dr. Aldrich's model was developed mainly for predicting the failure of landfill liners, but there are other factors to consider when determining total cost of a waste.

The Human Systems Center (HSC) located at Brooks AFB, San Antonio, TX published a cost estimate of the total cost to the Air Force Materiel Command (AFMC) resulting from the use of EPA-17 chemicals in June of 1994 (19). Ozone-depleting substances were not included in the study due to their scheduled phase out and other

EPA-17 substances that are no longer used were also excluded. The cost estimate was based on seven cost driving factors: procurement, handling, management, personal protection equipment, medical, potential legal/environmental liability, and disposal (19:2-1). When addressing each of the factors every cost attributable to the driver was considered. For instance when assessing the cost due to personal protective gear, not only was procurement costs of the equipment considered but also loss of productivity due to the wearing of the equipment. The results of the study for the EPA-17 are shown in Table 2-1.

Table 2-1. EPA 17 Cost Estimate (19:7-2)

SUBSTANCE	COST/LB
Cadmium	$ 67.57
Chromium	$ 26.45
Cyanide	$ 27.30
Isocyanates	$ 129.07
Methyl Ehtyl Ketone	$ 33.17
Methyl Isobutly Ketone	$ 98.64
Methylene Chloride	$ 7.47
Nickel	$ 26.42
Perchloroethylene	$ 7.57
Toluene	$ 75.06
Xylene	$ 137.37

The majority of the managers indicated that their first priority for pollution prevention are those projects that are compliance driven (See Appendix A). Secondly they choose projects that will affect future regulations that might be pending, and lastly considerations go to those projects that have no requirements driving their selection, but might be excellent in preventing pollution. This list of priorities follows the Air Force Instruction 32-7001 *Environmental Budgeting* which gives guidance and responsibility

for planning environmental budgets. The AFI instructs managers to request funding for three different levels of pollution prevention:

Level P1: Ozone Depleting Chemical (ODC) and Legal Requirements
Level P2: Meet Future Air Force Goals, Policies, and Legal Requirements
Level P3: Beyond Air Force Goals and Legal Requirements (6:9-10).

Projects are typically funded by level starting with P1 down to P3. If money runs out before all projects are funded it is normally levels P2 and P3 that remain without resources necessary for implementation. Fall out money at the end of the fiscal year is used for the unfunded projects if additional resources become available (31).

If there are not enough resources to select all compliance driven projects decisions must be made as to which projects would bring the most benefit. If there is money to fund other levels of projects besides compliance driven projects, managers must face the hard decision of which projects to select. A standard method for solving these allocation problems is needed.

Multicriteria Decision Making

In order for there to be a decision there must be at least two alternatives. For instance, should you buy a car or not buy a car. It is easy to see that a decision must be made here, but often the decision is not easy. Most car buyers have certain features that they would like for the car to have. Does the buyer want a cheaper car with lower gas mileage or a more expensive car that gets better gas mileage? What color should the car be? As the number of attributes increases, the decision becomes much more difficult.

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This car buying example allows for a simple introduction to multicriteria decision making terms that will be used throughout this chapter and the remaining chapters of this thesis. In this scenario the decision maker's *goal* is to purchase a car (5:5). His alternatives are to not buy the car or to purchase one of the many different models available. The *objective* of his goal might be to have good transportation, spend relatively little, and get good gas mileage (5:5). Color and style, considered *attributes,* might also be important factors. Attributes are a set of measures that indicate the degree to which the objective is met (20:4). Careful consideration of all aspects of the problem, including the pertinent objectives, can lead to discovery of hidden alternatives. (5:6). If the buyer wants only a blue car, then every model that is not blue is no longer an alternative. Goals, objectives, and attributes that guide a decision maker when faced with a hard decision can all be referred to as *criteria* (36:17).

Multicriteria decision making takes place in an "environment where multiple factors are to be considered in making the final selection" (37:223). In selecting pollution prevention projects the decision makers must look not only at the economics of the alternatives but how well the alternatives prevent pollution. Depending on the objectives of the decision maker, many other factors could also play a role. There are many techniques available for use in multicriteria decision making. It is beyond the scope of this paper to cover them all; only those relevant to the research will be covered.

Multicriteria Decision Making Techniques

Goal Programming

Goal Programming is a linear and integer programming technique for solving multi-objective problems (29:19). This method attempts "to minimize the set of deviations from prespecified multiple goals, which are considered simultaneously but are weighted according to their relative importance" (36: 281). This approach was recommended to the Water Resources Council as a solution to the public water resources project selection problem (29:19). Economic and environmental quality objectives were conflicting therefore a method was needed so that consideration would be given to these multiple objectives when selecting and planning projects (29:19). Goal programming allows for this consideration while at the same time keeping proposed solutions within the budget.

Displaced Ideal Model

Compromise programming chooses the alternative that minimizes the distance between the chosen alternative and the ideal solution (11:133-136). The displaced ideal model (DIM) is a special type of compromise programming which defines the ideal solution to be a composite of the best outcomes in a number of decision criteria (25:2-2). McPherson and Watts used this method to propose to the Air Force a means of prioritizing pollution prevention projects. This model allows for each individual user to

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have personal management strategies incorporated into the process so that objectives can be met.

Outranking Technique

This method stemmed from the awareness of the false sense of precision which can so easily be associated with numerical representations of the attractiveness of decision options, particularly if they emerge from a computer (35:74). Outranking is based on a set of well defined options that can be defined in terms of attributes in which each option can be measured (35:74).

Value-Based Technique

This technique relies on the use of utilities. Utilities are "subjective benefits derived by the decision maker from the achievement of the stated good or objectives" (18:19). Value based decision making uses the preferences of the decision maker to rank options. This technique involves having the decision maker select a logical set of principles to work by. Therefore, the utility derived for each alternative is an indication of its relative desirability (20:4). The alternative with the highest utility is preferred to the one with the lower utility; however the difference between the expected utilities has no meaning unless the utility function also happens to be a measurable value function (20:4).

Decision Analysis

Decision analysis is a methodology used to aid decision makers in the task of solving hard, complex problems. With decision analysis, a decision maker can take action with confidence gained through a clear understanding of the problem (5:2). Decision analysis provides guidance for making hard decisions when faced with uncertainties. It does not solve the problem; it merely provides a logical framework for decision making based on what the decision maker knows, what the decision maker can do, and what the decision maker prefers. This systematic procedure provides an easier method for making a better decision (1:170). The decision analysis process is made up of four steps:

Step 1 Identify the Problem.

Identifying the *correct* problem is the first and most important step in decision analysis. A surface problem could be hiding the real issue. Careful identification of the problem at hand is key to a good decision analysis (5:5).

Step 2 Identifying Objectives and Alternatives

What is important must be identified. What objectives should be maximized and minimized? Careful consideration of all aspects of a problem, including pertinent objectives can lead to the discovery of alternatives that were not obvious at the onset (5:6).

Step 3 Decompose and Model the Problem

      The first step in modeling the problem is to structure the problem in smaller more manageable pieces. The purpose of this phase is to illustrate the decision maker's alternatives, uncertainties, and values (1:171). Decision analysis uses two approaches for structuring problems: the influence diagram and the decision tree. Both approaches are valuable and can be used together. Decisions to be made, uncertain events, and the values of outcomes are all represented by different shapes in the influence diagram. Squares represent decisions that need to be made, circles represent uncertainties, and rectangles with rounded corners represent values. The shapes, which are referred to as nodes, are linked by arrows to illustrate different relationships (5:34). Properly constructed influence diagrams have no cycles, regardless of the starting point, there is no path following the arrows that lead back to the starting point (5:37). Figure 2-1 illustrates a simple influence diagram.
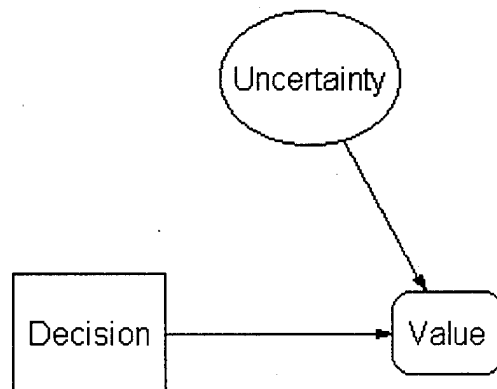
Figure 2-1. Influence Diagram

While influence diagrams are excellent for showing the structure of a problem, it hides many of the details. A decision tree displays possible outcomes from decisions on branches emerging from decision nodes and possible pathways from uncertain events on branches coming from circles (5:50). All possible paths that can be taken by the decision maker are represented on a decision tree. Figure 2-2 illustrates the decision tree.
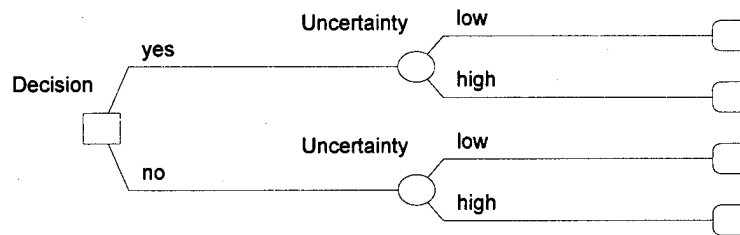

Figure 2-2. Decision Tree

Step 4 Choose the Best Alternative

Decision analysis works on expected value so the outcome with the highest expected value is the preferred alternative. This process is iterative and once a model has been built, sensitivity analyses can be performed. Sensitivity analysis answers "what if" questions about different variables (5:7).

Decision analysis involves many techniques used in multicriteria decision making such as utility and value functions. The method is extremely useful for tackling these types of problems when more than one factor is important.

III. Methodology

Overview

This chapter describes the procedure used for developing a decision tool to select optimal pollution prevention projects within a constrained budget. I chose to use decision analysis for my methodology due to the advantages of this method described in Chapter Two. Decision analysis breaks the problem into component parts, thereby allowing the decision maker to focus on the critical aspects associated with the alternatives. This method merely provides a framework to aid the decision maker.

The four steps that make up decision analysis were presented in Chapter Two. Step one, determining the problem, as stated in Chapter One, is:

> *There is currently no Air Force standard for selecting which recommended*
>
> *projects should be implemented in order to obtain the greatest environmental*
>
> *benefits for the dollars spent on capital costs.*

The remainder of this chapter will focus on steps two and three: *Selecting the Decision Criteria* and *Modeling the Problem.* I will determine the criteria that should be used when selecting projects based on the values of the pollution prevention managers obtained from a survey developed and administered during the research of this project. I will then build a model to aid decision makers in selecting which pollution prevention projects to implement. Step four- Choosing the Alternative- will be illustrated in Chapter Four, Analysis and Findings.

Selecting Criteria

The goal of this thesis is to develop a model that aids decision makers in selecting pollution prevention projects within a constrained budget. It has been stated earlier that this model should select the best mix of projects. The term "best" is subjective but certainly depends on several criteria including both the costs and benefits of each pollution prevention project.

To determine these criteria, a questionnaire was sent out to base level pollution prevention managers. The purpose of the questionnaire was to determine the objectives of the decision makers when selecting pollution prevention projects for their installation. A discussion of how projects are currently selected can be found in Chapter Two. Figure 3-1 presents the questions asked in the survey.

QUESTIONNAIRE FOR POLLUTION PREVENTION PROGRAM MANAGERS

1.a. When selecting pollution prevention projects to implement, is your choice based solely on payback period?

1.b. If not, what other factors do you consider?

1.c. If yes, why do you not consider other factors?

2.a. Do you feel the payback period is an adequate measure for choosing the best pollution prevention projects?

2.b. Please state why or why not.

3.a. Do you feel that using another method besides payback period would result in significant changes in pollution prevention projects chosen?

3.b. What other factors would you like to see used to select projects?

4. Does your budget limit the number of projects that you implement in a given year?

5. If you were to choose projects based on environmental benefits do you (would you) consider mainly human or ecological effects of the waste eliminated?

6.a. Is manpower a major consideration when choosing projects?

6.b. Please state why or why not.

Figure 3-1. Pollution Prevention Questionnaire

These questions were chosen to identify the specific criteria important to the actual decision. Since Air Force guidance recommends that the Payback Period be used for selecting projects, I wanted to determine if this method was being used in the field (9:2.2.4). NPV has been shown to be superior to the Payback Period when selecting pollution prevention projects so I also wanted to determine if pollution prevention managers were using this method if not the Payback Period. (See Chapter Two for a discussion of NPV). Other questions were geared so that the managers would provide criteria important for selecting projects.

Sixty questionnaires were sent out to base-level pollution prevention managers. Thirty-three percent returned the completed questionnaire. A summary of responses can be found in Appendix A. The results of the questionnaire showed that the majority of decision makers have two main objectives when selecting projects: 1) demonstrating positive net worth in order to obtain funding and 2) maximizing waste volume reduction. Decision makers most often struggle with choosing between maximizing one or the other.

Decision analysis is a method for solving such complex problems; what should be maximized and minimized in order to receive the highest expected value. The remainder of this chapter will focus on modeling the problem of selecting pollution prevention projects within a constrained budget in order to select the optimal group of projects for implementation.

Building the Model

The model was built using DPL™ software. DPL™ is a software package designed to build analyze, and conduct sensitivity analysis of decision problems (1:2). Chapter Two described the use of influence diagrams and decision trees which will be used to construct the model. DPL™ allows the design of the influence diagram and then constructs the associated decision tree. After all inputs are entered, DPL™ can calculate the expected values for each alternative, indicate the alternative with the highest expected value, and facilitate further analysis.

As stated earlier, the first step in building the model is to break down the problem into smaller more manageable parts. The overall decision of which group of projects to select can be broken down into smaller decisions such as, "Do I select Project 1?" This is the first building block of the influence diagram.
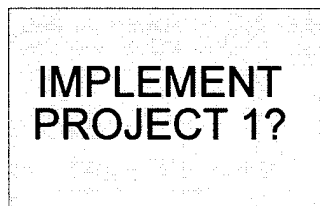
IMPLEMENT
PROJECT 1?

Figure 3-2. Decision Node

Figure 3-2 represents a decision node for the model. The decision nodes will vary according to the number of projects from which the decision maker must select. The next step is to build the value nodes for the criteria involved.

26

<u>Financial NPV</u>

Research described in Chapter Two indicates that using Net Present Value (NPV) is the optimal economic strategy for showing a project's worth. In order to calculate the NPV of a project, five items must be known: the operating cost before the project is implemented, the operating cost after the project is implemented, the capital cost of acquiring the project, the interest rate, and the horizon of the project (17:71-72). These figures are easily obtainable and can be requested in the statement of work when hiring a contractor to perform an opportunity assessment. Contractors providing the information with the OA will reduce the time required for the decision maker to enter data into a model.

As one of the criteria used to select projects, the NPV value is added to the influence diagram as shown in Figure 3-3.
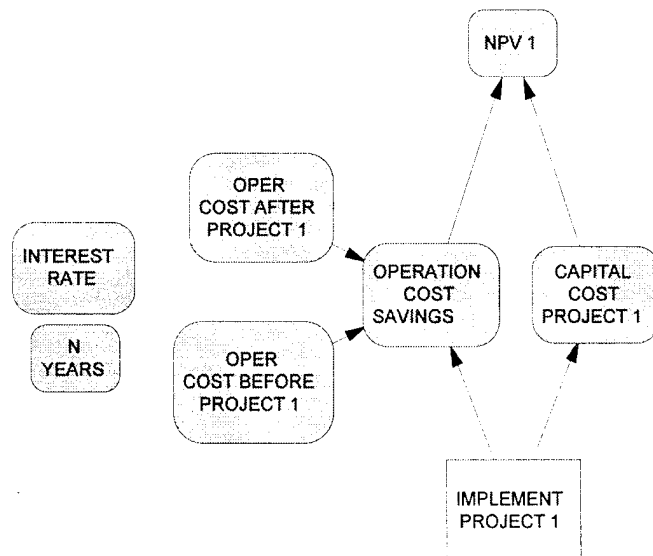

Figure 3-3. Financial NPV Nodes

The arrows (or influences) pointing from the decision to the value nodes indicate a relevance for making that decision. Arrows pointing from one node into another indicates that the information is needed to assess the value of the following node. The value nodes, Interest Rate and N years, are constants that are needed to determine the NPV but are not influenced by any other event. Therefore these unconnected value nodes can be referred to as constants.

Hazardous Waste Dollars NPV

Also presented in Chapter Two were the economic benefits derived from reducing pollution. These benefits include the costs eliminated due to reduced disposal, safety requirements, procurement costs, and legal liability. These costs are more difficult to address since they are less tangible than the financial procurement costs of a project. Research provided by the Human Systems Center at Brooks AFB, San Antonio TX (See Chapter Two) allows these less tangible costs to be addressed. This study is significant because it associates a dollar figure with a certain amount of waste for a given chemical. This enables a pollution prevention manager to calculate a better estimate of the amount of money saved when eliminating or reducing a waste stream. Knowing the amount of waste reduced can produce a dollar figure. Reduced waste cost savings and the previous NPV can now be combined. Only seventeen chemicals were studied by HSC, therefore, it would be beneficial if more chemicals were examined to determine the total costs associated with their use.

Since there is limited data available, more research would be required before the contractor could provide a dollar per volume of waste figure with the opportunity assessment for input into the model for every chemical and hazardous waste addressed. As research continues, this information will be available and therefore should be requested in a statement of work.

To determine the economics of the less tangible benefits, the volume of waste reduced for each project can be multiplied by the dollar figure associated with the type of chemical involved. Multiplying pounds by dollars per pound results in a dollar figure saved from reducing this amount of waste. These calculations are based on a yearly amount and will yield annual savings which can be converted to a net present value for a given horizon. The financial NPV for the procurement of the projects itself can then be added to the total NPV for the volume of waste reduced to get an overall total NPV for each project.

The nodes based on the NPV for the amount saved by reducing a certain amount of waste can now be added to the model as shown in Figure 3-4.
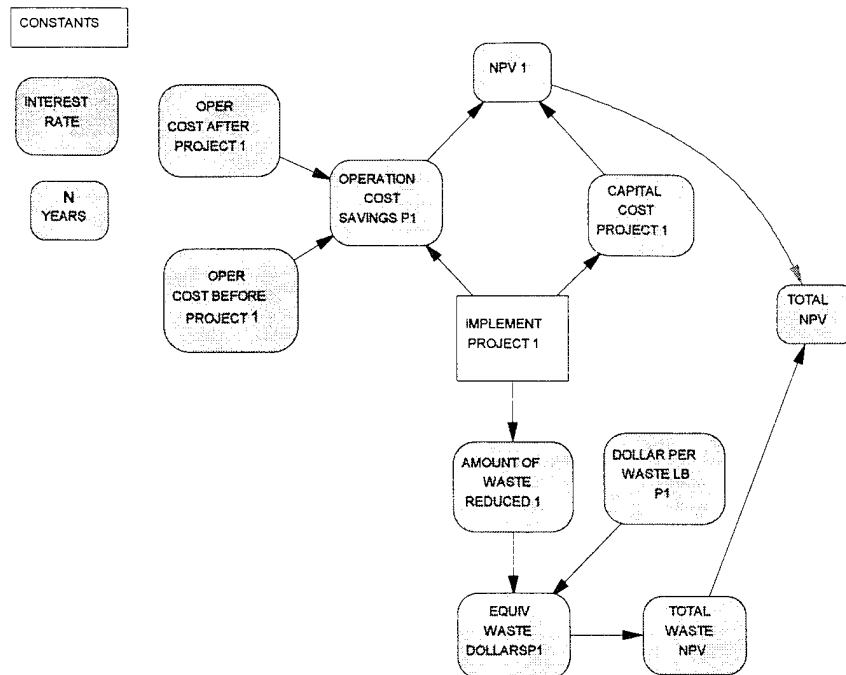
Figure 3-4. Hazardous Waste Dollar Nodes

The influence diagram shows that the Amount of Waste Reduced and the Dollar Per

Waste Pound influence the Equivalent Waste Dollars. DPL™ allows for calculations to

be inserted into nodes so the Equivalent Waste Dollars node multiplies the two

influences. The result from this node is then entered into the Waste NPV node to

calculate the NPV of the dollars saved by reducing the waste. This NPV can be added to

the financial NPV associated with procuring the project to result in a total NPV for the

entire project.

It was stated earlier that the two main objectives of the decision makers

questioned indicated economic feasibility and environmental benefits as the most

important. The influence diagram is now constructed to consider the monetary aspects of the project and so environmental benefits must be added.

Environmental Benefits

In addition to the volume of the waste reduced, the harmfulness of the waste was also a consideration that pollution prevention managers used to select pollution projects (see Appendix A.) They indicated that a more harmful waste should be addressed sooner than a less hazardous waste given equal volume reductions. For the model to take this into consideration, a hazardous ranking is multiplied by the pounds of waste eliminated from the waste stream. For instance, a project that eliminates 10 lbs of methyl ethyl ketone (MEK) would be more advantageous than eliminating 10 lbs of oil since MEK is a more hazardous substance. A way to account for this is to multiply each waste volume by a hazardous ranking. The MEK is multiplied by 0.9 and the oil 0.4, the notional hazard rankings for the two substances. Now the waste streams for each project would be 9 and 4 respectively. To maximize environmental benefits, MEK has a higher Hazardous Pound value than the waste oil.

Ideally, for this model, a prioritized list of hazardous materials would be given to the decision maker. Unfortunately at this time there is no such list available. According to ProAct, an environmental research office located at the Air Force Center for Environmental Excellence, Brooks AFB, Texas:

> When considering the relative hazard of a given chemical, one must define hazard. If hazard involves human exposure, then the amount, means of use, and the conditions under which a chemical is used will affect the degree of true hazards. If hazard is approached from the environmental side, then stratospheric

ozone, green house effect, volatile organic chemical, particulate, etc. need to be addressed. In short, we have a listing of typical chemicals, but not a hazard index (24).

Since there is no relative ranking available at the present time, the model will rely on a subjective hazardous ranking, from the decision maker, ranging from 0-1, with zero indicating no hazard and one indicating the most hazardous. Allowing a subjective input will let the decision maker use his own knowledge of the objectives of his environmental office to affect the model's outcome. This method of using a hazardous ranking places each project's eliminated waste stream into equivalent pounds for easier comparison.

Adding environmental benefits to the model was an easier task since the value node for Amount of Waste Reduced had already been created. All that was needed was a node to account for the subjective input of the decision maker:
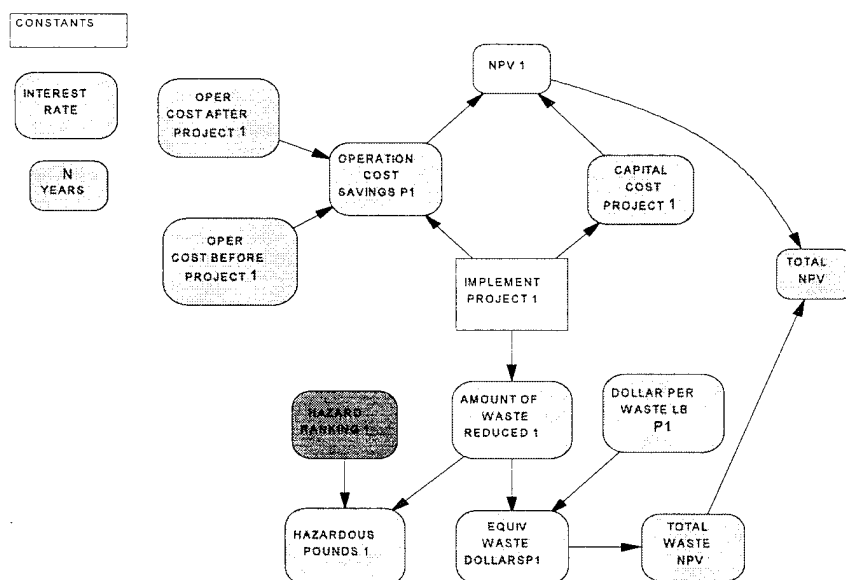

Figure 3-5. Environmental Benefit Nodes

Inside the Hazardous Pounds node, the Hazard Ranking is multiplied by the Amount of

Waste Reduced to give the equivalent pounds of hazardous waste that can be compared to

other projects. To demonstrate how projects are linked, Figure 3-6 shows two projects
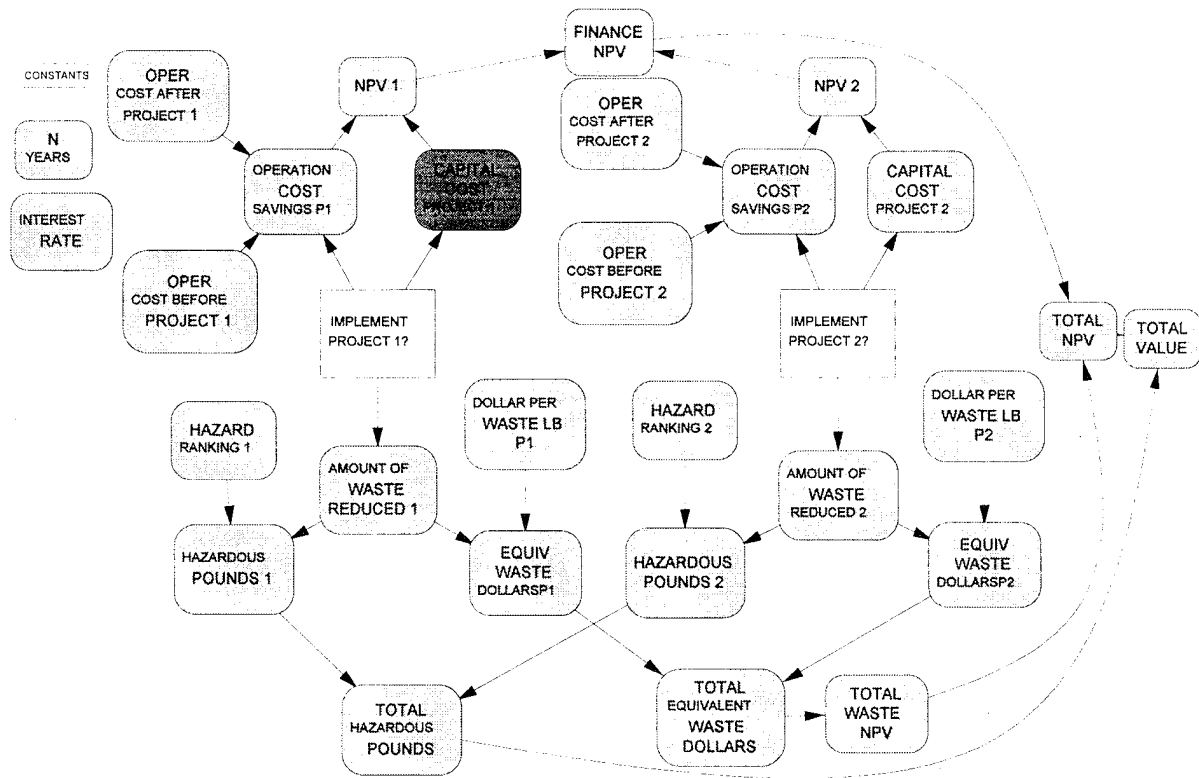
being considered.

Figure 3-6. Combined Projects

Figure 3-6 shows that as projects are added, the equivalent waste dollars from each

project are summed together and then the NPV for these dollars are computed. The

figure also demonstrates that the Financial NPVs for each project are added before being

added to the Total Waste NPV. The result is the Total NPV. Total Hazardous Pounds

are also added so that the final strategy of projects chosen will show the Total NPV and the Total Hazardous Pounds for the selected strategy.

<u>Capital Budgeting</u>

Another factor considered when building the model was that all pollution prevention managers must work within a budget. The model would not be beneficial if it did not select the best projects within a given budget. If the model just ranked the projects in order of attractiveness the results would be less valuable unless the decision maker had the resources to implement all of the projects. Capital budgeting offers a method to evaluate the economic attractiveness of proposed pollution prevention projects to ensure that benefits derived from the allocation of investment dollars are maximized (32:447).

In order to have the model select the best group of projects for the given budget, a constraint must be added to the model. To do this I created a node for the total capital cost of the projects. A constraint was then added to the model which instructs the decision policy not to include any group of projects whose total capital cost exceeds the constraint, but rather assigns those particular strategies a value of negative one. The result is the final influence diagram for two projects shown in Figure 3-7. Any number of projects can theoretically be added.
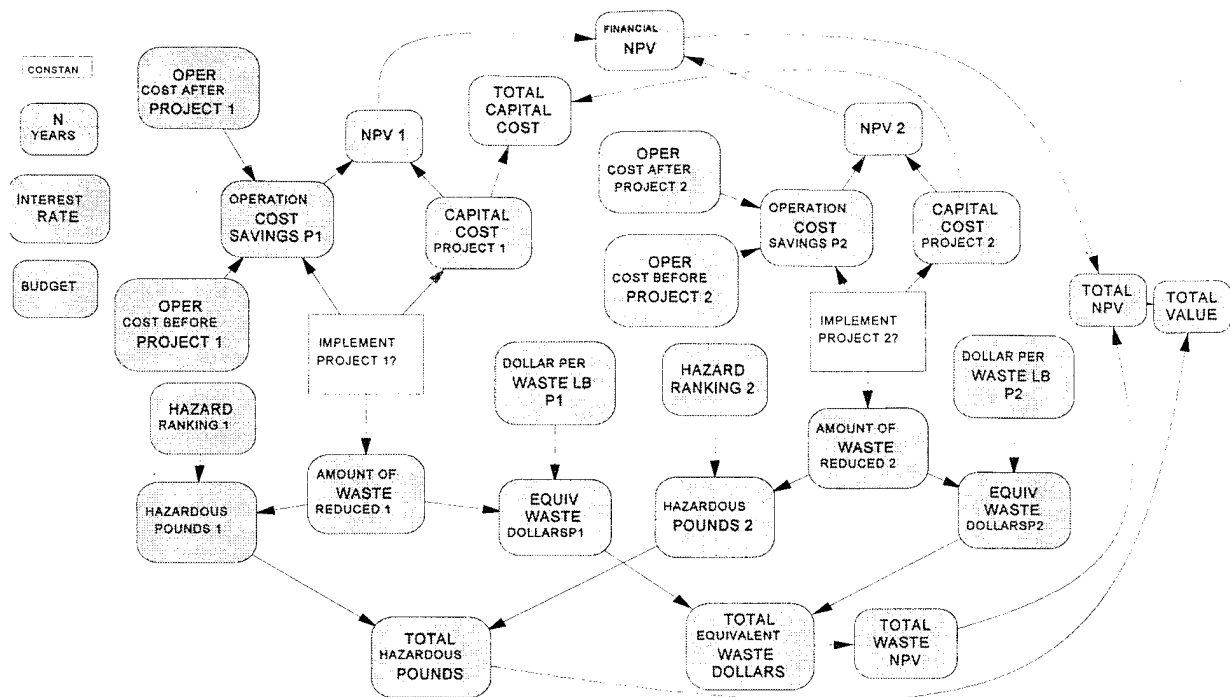
Figure 3-7. Capital Budgeting Node

Trade Off of Attributes

      The essential problem in multi-objective decision making is deciding how best to trade off an increased value of one objective for a lower value of another (5:436). The method used in this model is based on assessing individual attribute scores for the alternatives. Then a project's overall score can be calculated as a weighted combination of its scores (5:439). This method is a form of the Value-Based Technique discussed in Chapter Two.

      In this model, the two attributes that must be traded off are Total NPV and Total Hazardous Pounds. Total NPV is the total of the projects' Financial NPV and the Hazardous Pounds NPV. Total Hazardous Pounds is the sum of the hazardous pounds

reduced by the selection of projects. These two attributes must be scaled in order for the two to be directly comparable. This was done using proportional scoring:

$$S_{Ai} = (\frac{X_{Ai} - LowestValue_A}{HighestValue_A - LowestValue_A})$$

S_{Ai} represents the score of the attribute and the alternative is represented by the lowercase i. *LowestValue*$_A$ and *HighestValue*$_A$ represent the highest and lowest values of each of the attributes for the projects involved (5:439). Lowest value scores are determined by taking the lowest NPVs and lowest Hazardous Pounds and summing them until the capital budgeting constraint is reached but not exceeded. This group produces the lowest possible alternative value that the model would ever choose. (It is possible to select only one project thus making the lower limit on NPV the value of one project, but decision analysis works on highest expected value so it would always try to maximize outcomes and select as many projects as possible.) The Highest Value is determined by adding up values until the capital budgeting limit is surpassed. This value would be impossible but it gives a realistic upper bound. It is important to keep the upper and lower bounds close to the range of actual calculated values for increased sensitivity.

Once the two attributes are on a comparable scale they can be linearly added to produce a final score of the project. Weighting is introduced here in order to incorporate the decision maker's values on which attribute is more important. The weight is scaled from 0 to 1. The expected value for each group of selected projects comes from the following equation:

Expected Value=(Economic Weight*S_1)+((1-Economic Weight)*S_2)

Another method to select projects using this model is to build a dominance curve from the expected values. An alternative A is said to have dominance over alternative B if, for all i in i=1....n, $x_{Ai} \geq x_{Bi}$ and for at least one i, $x_{Ai} > x_{Bi}$ where x_{Ai} is the value of alternative A with regards to attribute i(35:23). By plotting scores of two attributes of each alternative, dominant and dominated alternatives can be identified. If one alternative clearly dominates another then the dominated alternative should not be chosen. Once the dominated alternatives are removed from the option set, the remaining alternatives are used to form the efficient frontier (35:24). A decision maker should choose the final alternative strategy from the alternatives on this frontier. Plotting Total NPV versus Total Hazardous Pounds for each mix of projects allows the decision maker to move systematically through the alternatives. This method also allows the decision maker to see how the result differs from different weightings; if economics is the only consideration then the chosen set of projects will have the highest NPV but not necessarily the highest hazardous pounds. (This is illustrated in Chapter Four.) An example of a dominance curve is shown below in Figure 3-8.
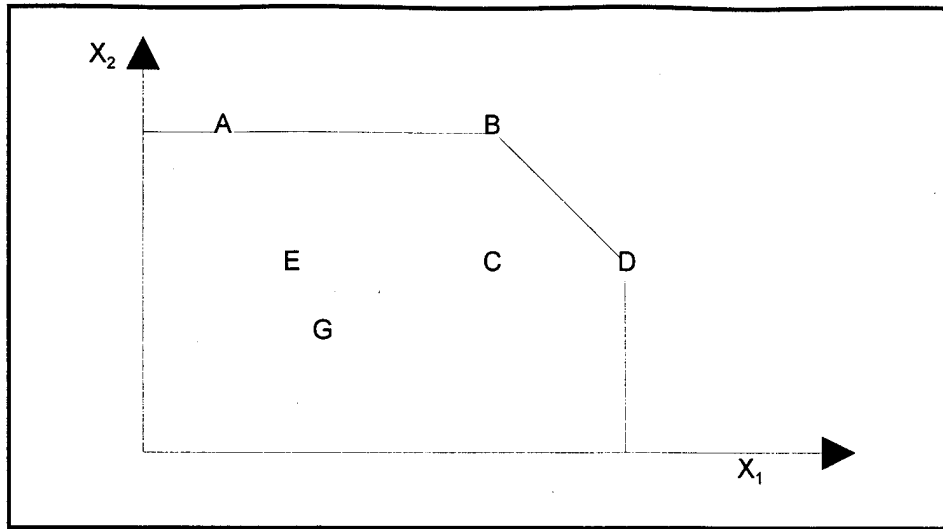
Figure 3-8. Dominance Curve (35:23)

In the figure E, C, and G are dominated. A,B, and D are not dominated, and form the efficient frontier (35:23). In order to create an efficiency frontier, the alternatives on the frontier are connected to form a convex hull. Depending on the importance of X_1 and X_2 and the willingness of the decision maker to trade off values, any of the three choices on the frontier may be an optimal solution.

Summary

Figure 3-9 shows the influence diagram for the problem of selecting pollution prevention projects within a constrained budget. The figure illustrates two projects as well as the constants used in the analysis. The figure illustrates only two projects, but the model will incorporate as many projects as are available to the manager. It is recommended to use the model on a per shop or some smaller scale basis rather than the entire installation. The model can incorporate as many projects as necessary, but this will

also increase the run time and analyzing the results will become more cumbersome for the decision maker.
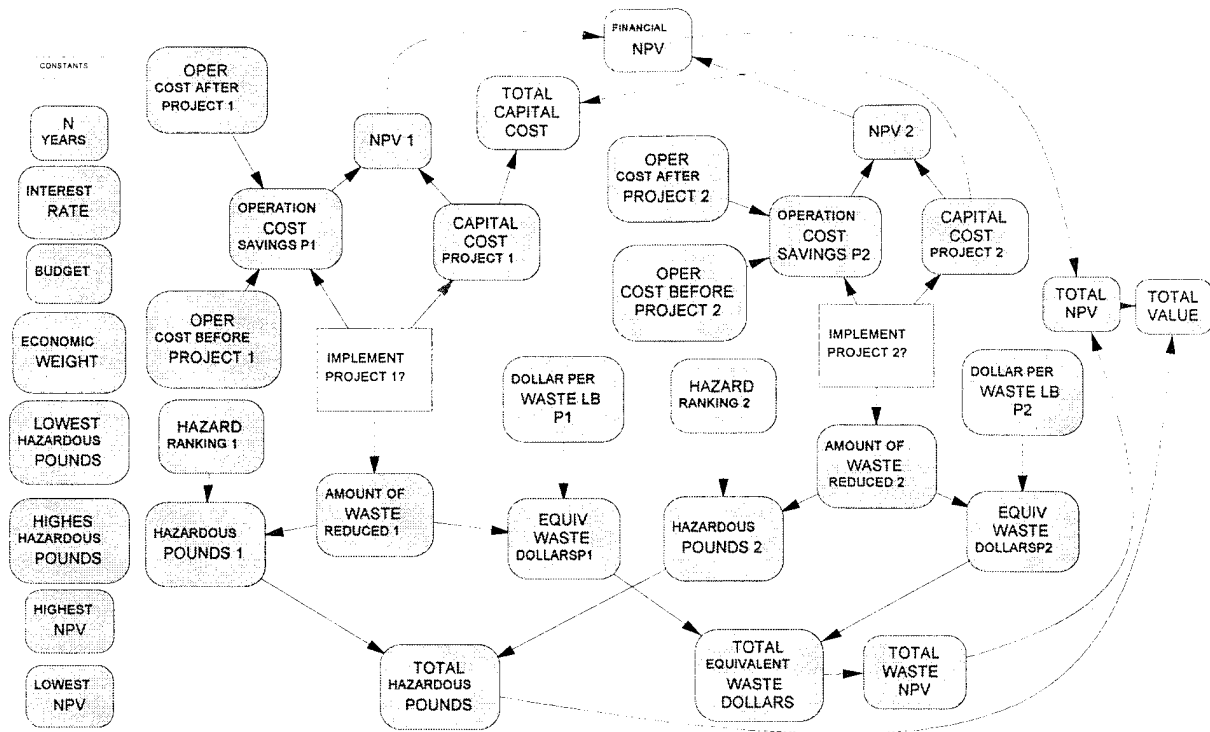
Figure 3-9. Complete Model

Since Decision Analysis maximizes expected value, final recommendation will be the group of projects that has the highest expected value while remaining within the given budget. Constants are entered by the decision maker. The economic weight constant is a weighting factor to account for the decision makers objectives concerning economic versus environmental considerations. A weighting factor of 1.0 ignores the value of reduced hazardous waste while a factor of 0.0 ignores the value of the NPV for the mix of projects. For both attributes to have equal consideration a factor of 0.5 is used.

Decision Analysis produces values for all feasible strategies. These values are used to produce a dominance curve. The dominance curve illustrates which strategies are the optimal strategy based on the decision maker's economic weight.

IV. Analysis and Findings

Introduction

The purpose of this thesis is to develop a model that will assist in selecting the optimal mix of pollution prevention projects to be implemented within a given budget. This thesis will use DPL™ to perform the quantitative analysis of this model.

Types of Analysis

Four types of analysis were performed on the decision support model: Decision Analysis, Value Sensitivity Comparison, Value Sensitivity Analysis, and Dominance Curve Analysis. The first three types of analysis can be accomplished within the DPL™ environment. Dominance Curve Analysis will be completed using Microsoft Excel and values from the decision policy analysis.

Decision Analysis

The Decision Analysis function calculates the expected value and identifies the optimal decision policy based upon values identified in the model and preferences indicated by the decision maker(1:37). DPL™ produces a decision policy diagram that illustrates the optimal decision strategy. This policy is determined by the expected values of the alternatives (1:37).

Value Sensitivity Comparison (Tornado Diagram)

Sensitivity analysis identifies variables that are most critical to the analysis of the model. Value Sensitivity Comparison shows how much the value of an alternative can vary with changes in a specific variable while all other variables remain unchanged(5:116). The Tornado Diagram is the graphical figure used to represent the values. The tornado diagram shows which variables should be examined more closely and which variables can be left at their base value (5:119).

Value Sensitivity Analysis (Rainbow Diagram)

Value sensitivity analysis calculates the change in the optimal strategy as one particular value in the model is varied. (1:474). The rainbow diagram is the graphical tool used to represent this analysis. This diagram provides indication of a policy change as a function of the changing variable (1:470). This analysis is an in-depth look at variables that were identified in the tornado diagram as critical to the model.

Dominance Curve Analysis

As described in chapter three, plotting scores of one attribute versus another for each of the different alternatives allows dominant alternatives to be identified. If one alternative clearly dominates another (see Chapter Two) then the dominated alternative will not be chosen. Once the dominated alternatives are removed from the option set, the remaining alternatives are called the efficient frontier (35:24). From this set the decision maker can clearly see the best strategies and the tradeoffs available.

Case Study

Ideally this model would be used by a pollution prevention manager faced with the task of choosing between recommended pollution projects. Because this model was built using data not currently available to the managers (i.e. managers have not requested this data in their opportunity assessments), notional data will be used to run the analysis. Table 4-1 gives the characteristics of the projects being compared.

Table 4-1. Project Selections

	Project 1	Project 2	Project 3	Project 4	Project 5
Capital Cost	$ 500.00	$ 650.00	$ 100.00	$ 350.00	$ 700.00
Savings from Operating Costs	$ 300.00	$ 300.00	$ 200.00	$ (50.00)	$ 250.00
Financial NPv	$1,343.37	$1,193.37	$1,128.91	($657.23)	$836.14
Pounds of Waste Reduced	300	400	600	480	300
Hazard Index	0.5	0.7	0.2	0.8	0.6
Dollar/lb of waste	$ 10.00	$ 8.00	$ 6.00	$ 8.50	$ 14.00
Total Hazardous lbs	**150**	**280**	**120**	**450**	**180**
Equivalent Waste Dollars	$ 3,000.00	$ 3,200.00	$ 3,600.00	$ 4,080.00	$ 4,200.00
Total Waste NPV	$18,433.70	$19,662.61	$22,120.44	$25,069.83	$25,807.18
Total NPV	**$19,777.07**	**$20,855.98**	**$23,249.36**	**$24,412.61**	**$26,643.32**

This data was chosen so that different strategies can be demonstrated. These strategies include selection of a project which has a negative Net Present Value and tradeoffs between projects based on higher reduction of NPV or higher reduction of Hazardous Pounds. Financial NPV, Total Hazardous Pounds, Equivalent Waste Dollars, Total Waste NPV and Total NPV are calculated by the model. The inputs consist of Capital Cost, Operating Costs Before and After the Project, Pounds of Waste Reduced, Hazard Index, and Dollar/LB of Waste. As stated in previous chapters, this input can be obtained

from contractors in the Pollution Prevention Opportunity Assessment. The only subjective input will be the hazard ranking. Total NPV and Total Hazardous Pounds have been put in bold to illustrate that these are the figures that are weighted and used to calculate the expected value of the optimal project selection strategy.

Decision Analysis

Running Decision Analysis within DPL™ produces the optimal strategy based on the given and calculated numbers. The constants used for the analysis are shown below in Table 4-2.

Table 4-2. Constants

BUDGET	INTEREST RATE	N YEARS	ECONOMIC WEIGHT
1500	10%	10	0.5
HIGHEST NPV	**LOWEST NPV**	**HIGHEST HAZARDOUS POUNDS**	**LOWEST HAZARDOUS POUNDS**
$95,161.27	$63,882.41	910	450

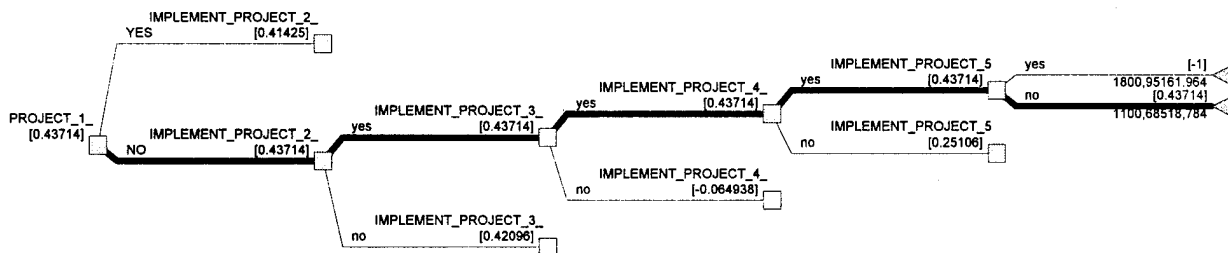The optimal decision strategy using this data is shown in Figure 4-1.

Figure 4 -1. Optimal Decision Policy 1

The optimal decision policy is to select Projects 2, 3, and 4 for implementation as the darkened lines indicate. Expected values used to rank the selections are given at the end of each node. The nodes ending with a negative one value mean that the budget constraint was reached and that path did not fall under the budget limitation. Negative expected values (excluding the value of negative one) indicate a path, that although feasible within the budget constraint, will never be chosen. This is due to the way the normalized scores were calculated. In an effort to decrease the sensitivity, values such as zero were not used for the lowest possible scores. Although a value of zero is possible, a manager would choose to do as many projects as possible for the budget allowed. The three values at the end of the tree represent the Total Capital Cost, Total NPV, and Total Amount of Hazardous Pounds for each strategy. Other nodes that have expected values but whose paths are not shown have possible outcomes but are not the optimal strategies. Later in this chapter these paths will be used to construct a dominance curve.

Although this is the selected optimal strategy for the values used, there might be input values that the decision maker might not feel are very accurate. Therefore, in order to determine how sensitive the decision is to changes in input value, a value sensitivity analysis is performed. The major advantage to using decision analysis for the selection of pollution prevention projects is that sensitivity analysis can determine which values are important to the decision. Values the decision maker feel are sensitive to the analysis can be changed into uncertainty nodes in the model and then run again to see if there is a change in the optimal decision policy.

Value Sensitivity Comparison

As stated earlier in the chapter, sensitivity analysis identifies variables that are the most critical in the analysis of the model. The first sensitivity analysis to be performed is the value sensitivity comparison which uses the tornado diagram to graph the results. The width of the bar reflects the effect the variable has on the expected value as it varies. The wider the bar is, the more significant effect it has on the expected value. The variables are graphed from the most significant, at the top, to the least significant, at the bottom (1:475-477). A shading change indicates the value where the optimal decision policy changes. The values shown range from lowest to highest for each criteria and the expected value associated with each. For instance, the tornado diagram shown in Figure 4-2 indicates that the most critical value is that of Amount of Waste Reduced for Project 4. The diagram shows that at some volume between 280 pounds and 680 pounds the optimal decision policy will change. The expected values associated with the outcome are also shown. For a volume of 280 pounds the expected value of the decision will be 0.25106 and at a volume of 680 pounds the expected value will be 0.77803 (all other values remaining the same). The tornado diagram for the case study is shown in four parts, but is one complete diagram.
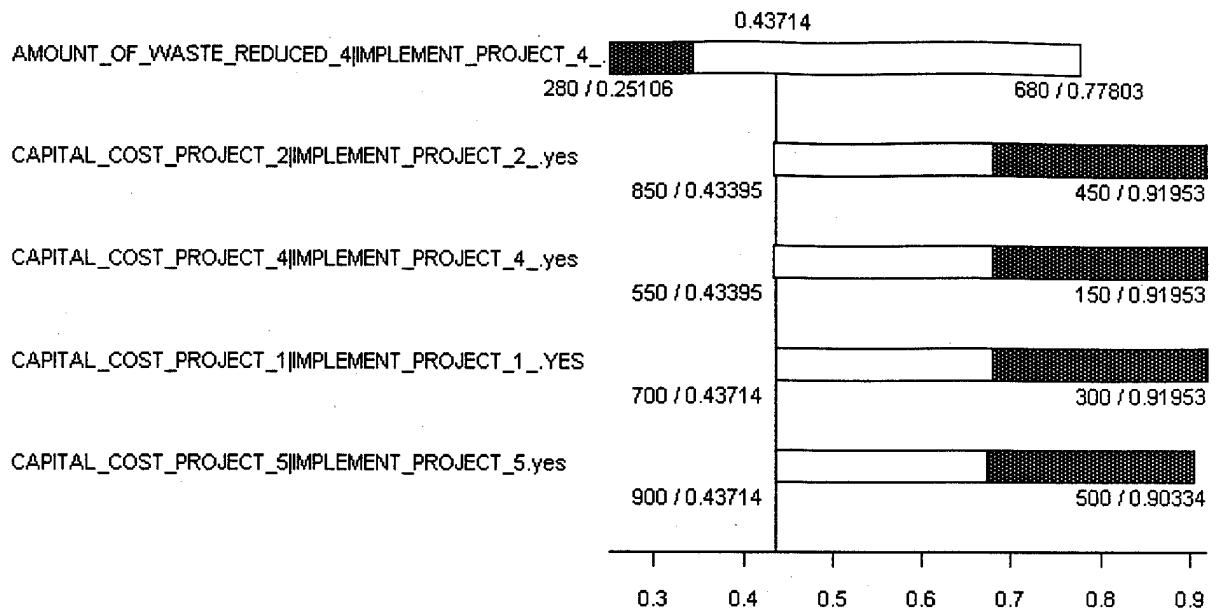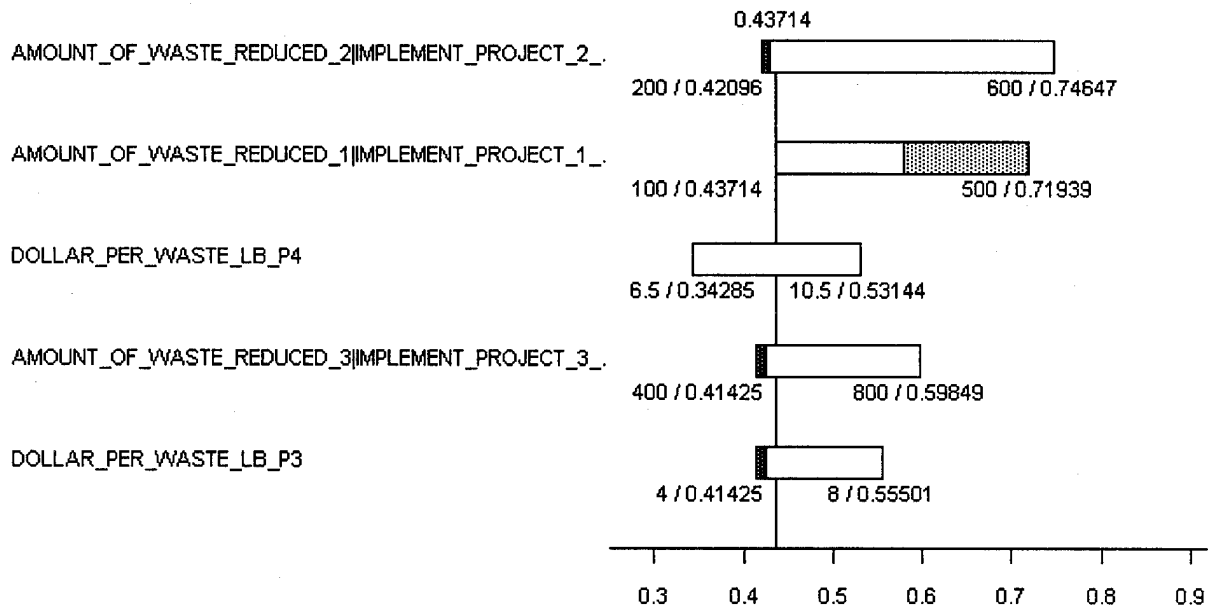
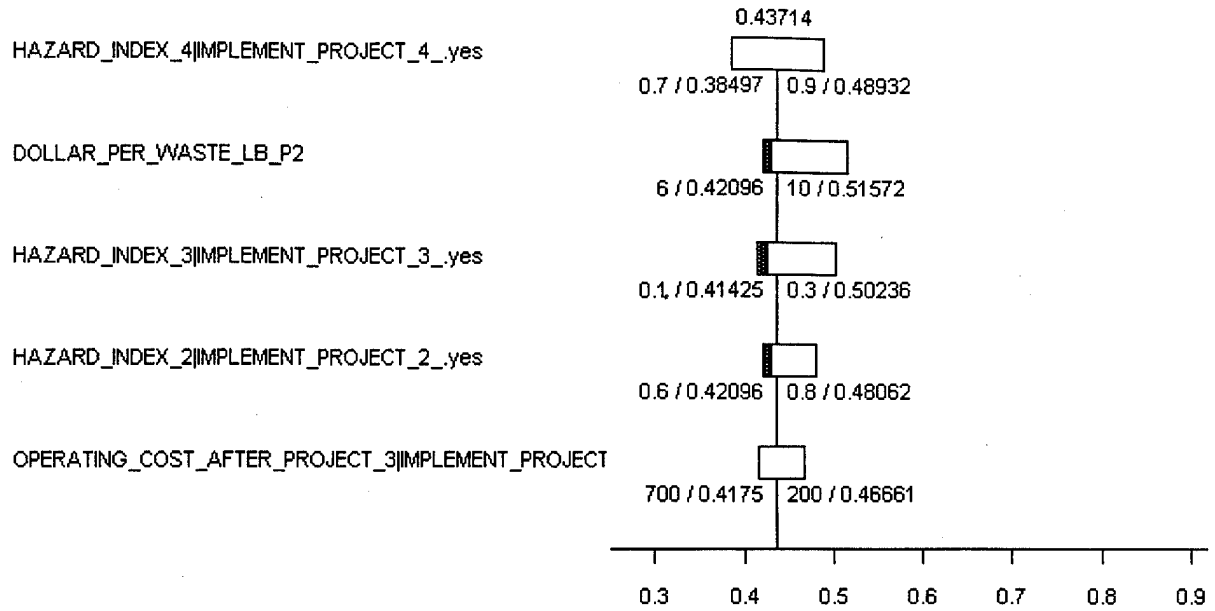**Figure 4-2.1. Tornado Diagram 1**

Figure 4-2.2. Tornado Diagram 2

0.43714

HAZARD_INDEX_4||IMPLEMENT_PROJECT_4_.yes

0.7 / 0.38497 | 0.9 / 0.48932

DOLLAR_PER_WASTE_LB_P2

6 / 0.42096 | 10 / 0.51572

HAZARD_INDEX_3||IMPLEMENT_PROJECT_3_.yes

0.1 / 0.41425 | 0.3 / 0.50236

HAZARD_INDEX_2||IMPLEMENT_PROJECT_2_.yes

0.6 / 0.42096 | 0.8 / 0.48062

OPERATING_COST_AFTER_PROJECT_3||IMPLEMENT_PROJECT

700 / 0.4175 | 200 / 0.46661

0.3 0.4 0.5 0.6 0.7 0.8 0.9

Figure 4-2.3 Tornado Diagram 3

0.43714

DOLLAR_PER_WASTE_LB_P5

12 / 0.43714 | 16 / 0.47989

OPERATING_COST_AFTER_PROJECT_4||IMPLEMENT_PROJECT

550 / 0.4175 | 150 / 0.45679

DOLLAR_PER_WASTE_LB_P1

8 / 0.43714 | 12 / 0.47318

OPERATING_COST_AFTER_PROJECT_2||IMPLEMENT_PROJECT

500 / 0.42096 | 100 / 0.45679

HAZARD_INDEX_5||IMPLEMENT_PROJECT_5.yes

0.5 / 0.43714 | 0.7 / 0.45357

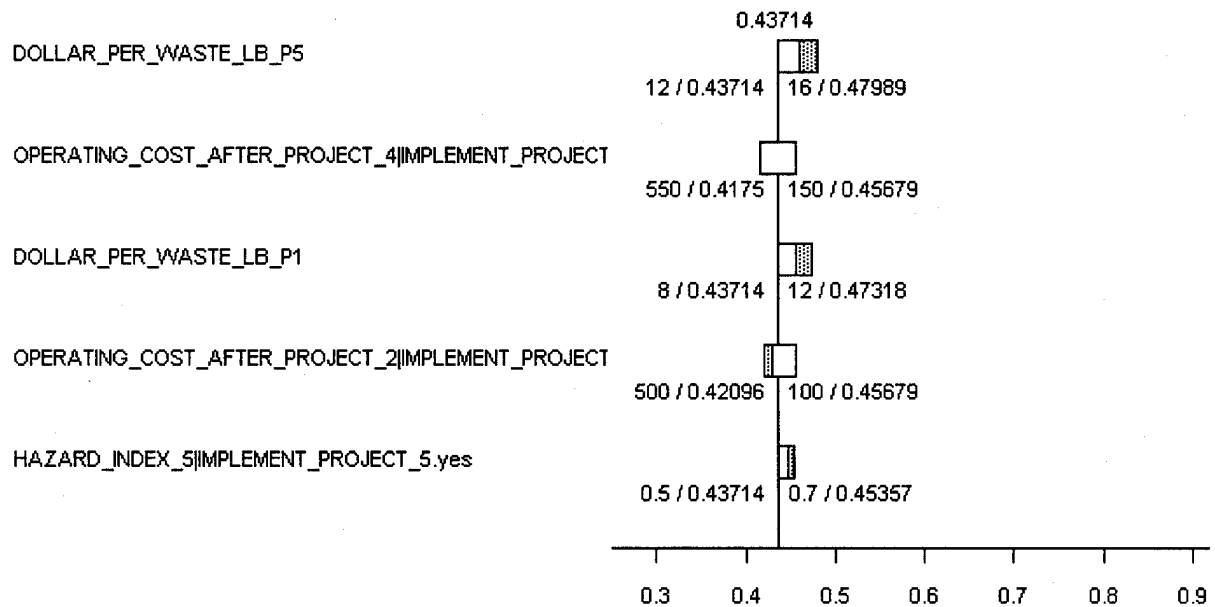0.3 0.4 0.5 0.6 0.7 0.8 0.9

Figure 4-2.4. Tornado Diagram 4

The values on the tornado diagram show the high and low value for the variable and the expected value for the outcome based on these values. From the tornado diagram it is evident that the most critical values are the Amount of Waste Reduced for Project 4 and the Capital Costs of Projects 1, 2,4 and 5. Other values which indicate a policy change with varied inputs are also significant and should be examined closer depending on the interests of the decision maker. The most useful aspect of the tornado diagram is it allows the decision maker to examine how sensitive the optimal decision policy is to the subjective inputs.

Sensitivity Value Analysis

Sensitivity Value Analysis (the rainbow diagram) can be used to examine the values determined to be critical from the tornado diagram at an in-depth level. It is up to the decision maker to determine the level to which the values should be examined. For the purpose of this case study, which is to demonstrate how the model is used, the five most critical values will be examined.

As stated earlier, the most critical value is that of Amount of Waste Reduced for Project 4. This value is critical because Project 4 has a negative NPV. A rainbow diagram will indicate exactly how many pounds of waste must be reduced for the project to be chosen. This is beneficial because many projects that are very beneficial to the environment are often not chosen due to the negative NPV. Using this model, the decision maker can see exactly how much volume reduction overrides the negative NPV. From the rainbow diagram shown in Figure 4-3, this value is approximately 370 pounds.

The decision maker only needs to worry about the policy changing if the amount of waste reduced could be lower than this amount. Otherwise, if all other values stay the same, Project 4 should be selected.
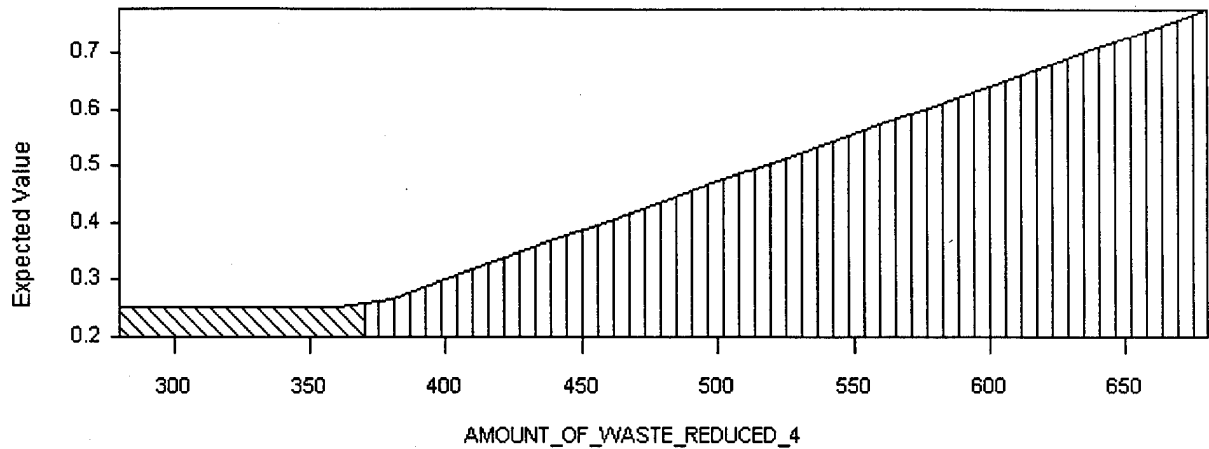

Figure 4-3. Amount of Waste Reduced Project 4

Capital Costs were also identified as being critical to the optimal decision policy. For Capital Cost of Project 1, the given cost in the notional data is $500.00. If the decision maker feels that the value of $500 given by the contractor will only vary plus or minus $200, the rainbow diagram (See Figure 4-4) shows that for this range the optimal decision policy will change where the two different patterns of shading meet. (On a color monitor the shadings are different colors.) In this case the value will be approximately $408. For the range entered here the decision policy only changes once, since at the high value of $700 the strategy is still a feasible strategy within the given budget. As mentioned earlier, the decision maker might be confident that the capital cost will not fall below the $408.00 so the decision maker will not choose to insert an uncertainty node for the value in the model. (This will be demonstrated later in the chapter.)
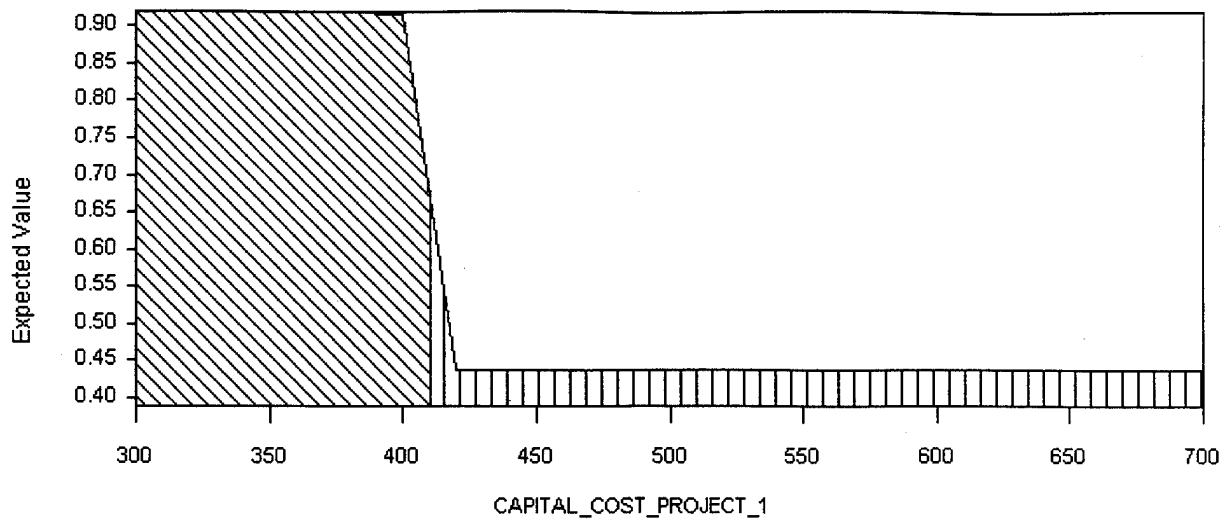
Figure 4-4. Capital Cost Project 1

To continue with the scenario, the decision maker might not be confident about the capital cost of Project 2 since it is a new innovative technology. The decision maker has seen the capital cost of this equipment as low as $500 and as high as $1200, but the average price seems to be approximately $650 which is what was quoted by the contractor. The rainbow diagram shown in Figure 4-5 indicates how these values will affect the optimal decision policy.
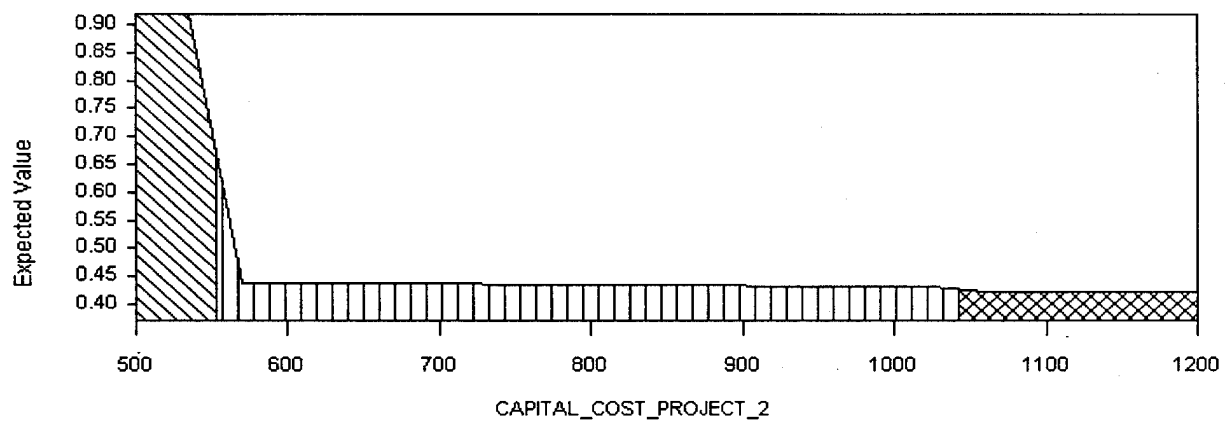

Figure 4-5. Capital Cost Project 2

For Project 2 the rainbow diagram shows that the decision policy changes at a value of $560 and a value of $1050. This diagram indicates that with two policy changes the decision maker might feel it best to change this value node to an uncertainty node in the model. This allows the model to consider uncertainties in values by assigning a probability distribution to the model.

Finally, the last two critical values, Capital Costs of Projects 4 and 5, are examined using the rainbow diagram. Figures 4-6 and 4-7 show the diagrams. Figure 4-6 indicates a policy change if the capital cost of Project 4 falls below $252.00. Once again the policy only changes once in the range of $150 to $600 since a value of $600.00 would still produce a feasible strategy. If the decision maker also felt as if the value could be much higher than $600 the same procedure would be followed as in the Capital Cost of Project 2.
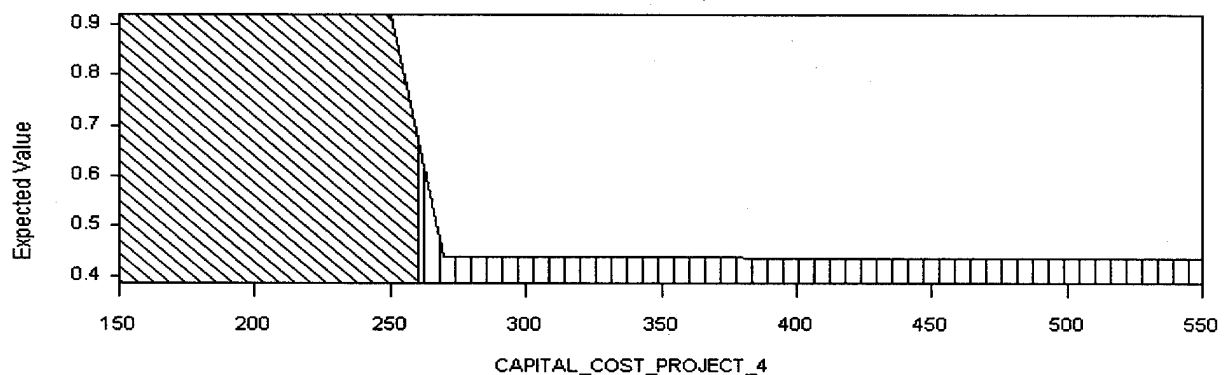

Figure 4-6. Capital Cost Project 4

Figure 4-7 indicates that the decision maker was also uncertain about the given value for the capital cost since the range was entered up to $1400. The rainbow diagram indicates though that as the value gets higher the optimal decision policy will not change. This is

consistent since the fact that the optimal decision policy does not select project 5. The diagram does indicate to the decision maker that if the capital cost decreases $100 the optimal decision policy *will* change. The decision maker might feel that a decrease of $100 for the capital cost is feasible and might also want to change this node to an uncertainty node. (This will be demonstrated later in the chapter.)
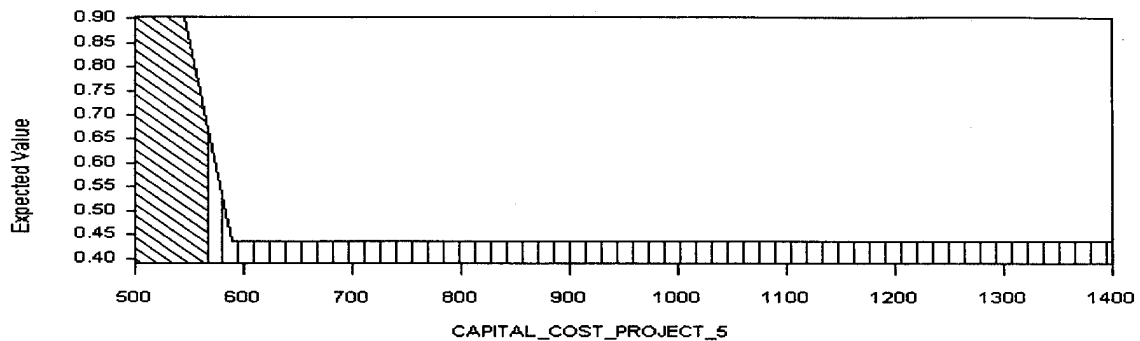
Figure 4-7. Capital Cost Project 5

Rainbow diagrams allow the decision maker to examine the values closely and see exactly where the optimal decision would change based on the input values. Although the tornado diagram did not indicate the hazard rankings were critical to the model based on the length of the line, they are still important due to their subjective nature. The rainbow diagram is useful here if the decision maker is not confident of the subject inputs. For instance the rainbow diagram for Hazard Ranking Project 1 is shown in Figure 4-8.
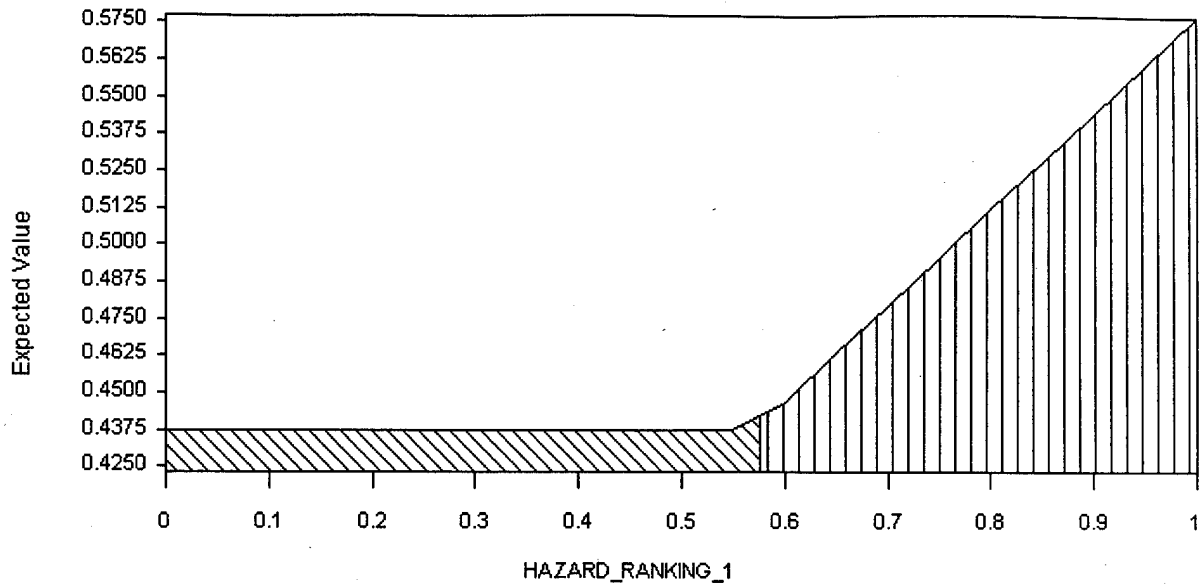
Figure 4-8. Hazard Ranking Project 1

This graph is extremely helpful to the decision maker because it shows that the

policy will only change if the hazard index for Project 1 rises above .57. This analysis is

also useful for the constants used when running the model. If the decision maker would

like to see how the optimal policy would change as the economic weight is varied,

indicating either a strong pull towards economics or environmental benefits, the rainbow

diagram is a useful tool. This is shown in Figure 4-9.
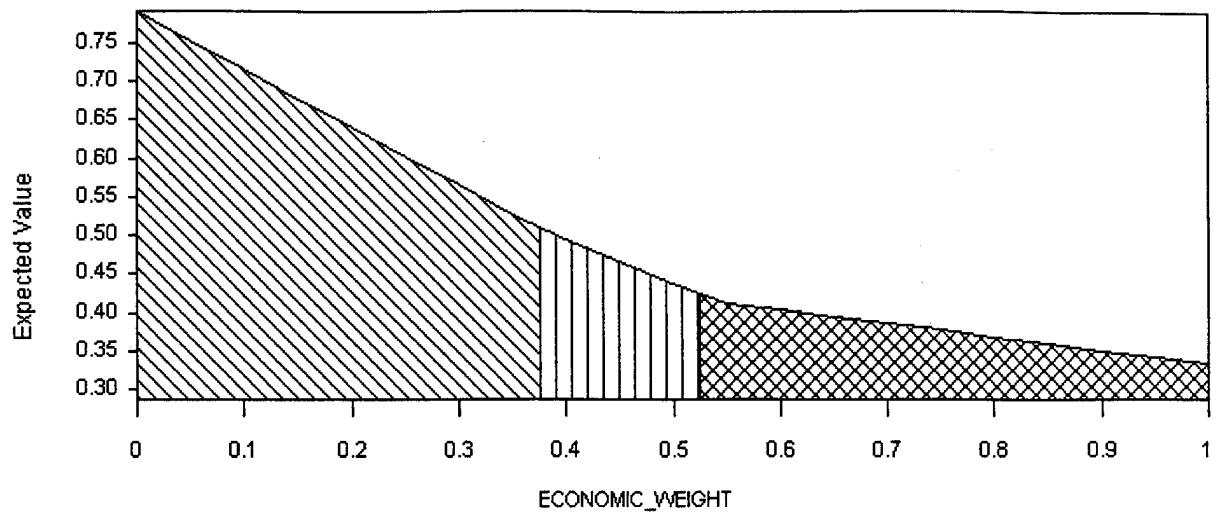
Figure 4-9. Economic Weight

This illustrates the fact that as the economic weight is varied projects will be selected either primarily by NPVs or Total Hazardous Pounds. Another way to see this is through the dominance curve which will be shown later in this chapter.

Adding Uncertainty Nodes

To illustrate how the model can accommodate uncertainty it was assumed that the decision maker was confident about the capital costs of Projects 1 and 4 and uncertain about Projects 2 and 5. The decision maker might also be uncertain about the Amount of Waste Reduced for Project 4 since it was determined to be the most critical value node. Therefore the value nodes for Capital Costs Projects 2 and 5 and Amount of Waste Reduced Project 4 were changed to uncertainty nodes. Figure 4-10 illustrates what the influence diagram would look like for one project if a value node was changed to an uncertainty node.
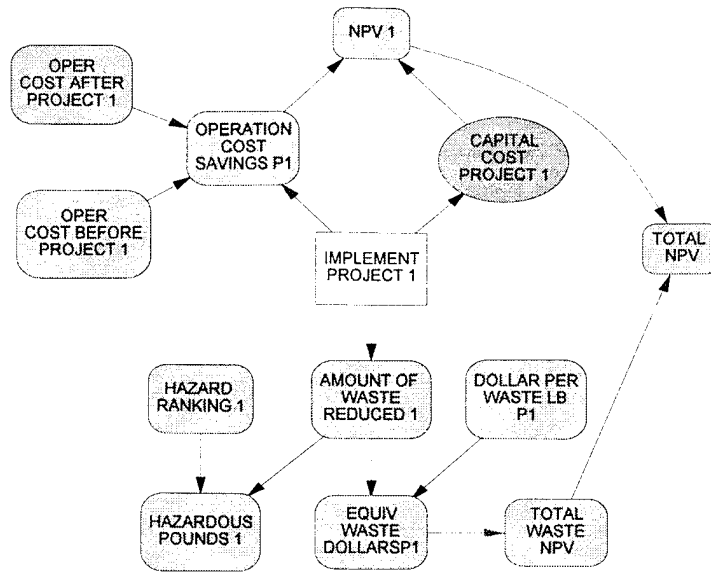
Figure 4-10. Uncertainty Influence Diagram

In order to use uncertainty nodes it is necessary to determine a probability

distribution that can describe the uncertainty. For this case study a triangular distribution

was used. This distribution is useful in this scenario since the decision maker should be

confident that the capital cost (and other data) provided by the contractor is accurate.

This distribution allows for the lowest expected cost and the highest expected cost. The

triangular distribution has three parameters: a,b, and c. The distribution extends from a

to b and peaks at c (which must lie between a and b). The only restriction on the

parameters is that a<c<b (1:417). The distribution is:

$$f_t(x|a,b,c) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} & \text{for } a \le x \le c \\ \dfrac{2(b-x)}{(b-a)(b-c)} & \text{for } c \le x \le b \\ 0 & \text{otherwise} \end{cases}$$

A named distribution such as the normal distribution can be used if there is enough historical evidence from the contractor to analyze how many times the quoted price has been correct. It is up to the decision maker to determine the best distribution based on knowledge of the contractor's previous work.

The triangular distribution values used for Capital Cost of Project 2 were $600 and $1200 with $650 being the expected value. Values for Project 5 were $500, $700 and $900. Amount of Waste Reduced for Project 4 used the values 280lbs, 480lbs, and 680lbs. Using uncertainty nodes the optimal decision policy the optimal decision policy changes. The selected strategy using this data is to select Projects 3, 4, and 5. Figure 4-11 shows the decision strategy.

IMPLEMENT PROJECT 1?   IMPLEMENT PROJECT 2?   IMPLEMENT PROJECT 3?   IMPLEMENT PROJECT 4?   IMPLEMENT PROJECT 5

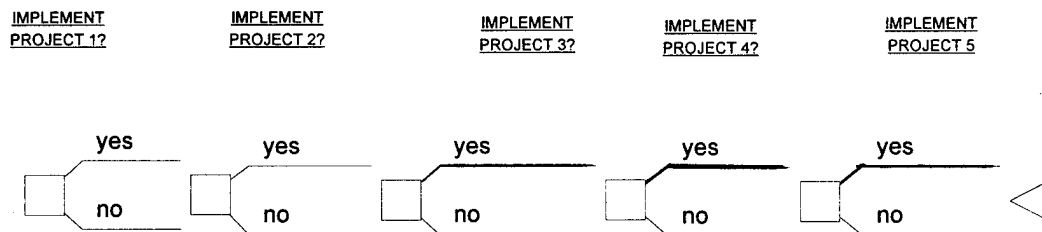yes   yes   yes   yes   yes

no   no   no   no   no

Figure 4-11. Uncertainty Optimal Decision Policy

The changing optimal decision policy indicates how useful decision analysis can be to select among projects. Decision Analysis can capture uncertainties of the decision maker and incorporate that into the decision process. This illustrates to the decision maker that

if given costs are questionable to a large extent, taking the time to return to the model and insert uncertainty nodes is crucial to get the optimal strategy.

Dominance Curve Analysis

Another method for selecting the optimal policy is through dominance curve analysis. The values used for this analysis are taken from the decision analysis. Enlarging the decision tree shown in Figure 4-2 gives all possible values for feasible strategies. This tree shows not only the optimal policy but every possible selection of projects that could be selected within the budget constraint. These values can be put into a spreadsheet (See Table 4-3) so that a dominance curve can be constructed.

Table 4-3. Strategy Values

Strategy	Selected Projects	Total Haz Pounds	Total NPV
1	1,2,3	550	$ 63,882.40
2	**1,2,4**	**814**	**$ 65,045.70**
3	1,2	430	$ 40,633.10
4	1,3,4	654	$ 67,439.00
5	1,3,5	450	$ 69,669.80
6	1,3	270	$ 43,026.40
7	1,4	534	$ 44,189.70
8	1,5	330	$ 46,420.40
9	1	150	$ 19,777.10
10	**2,3,4**	**784**	**$ 68,517.90**
11	2,3,5	580	$ 70,748.70
12	2,3	400	$ 44,105.30
13	2,4	664	$ 45,268.60
14	2,5	460	$ 47,499.30
15	2	280	$ 20,856.00
16	**3,4,5**	**684**	**$ 74,305.30**
17	3,4	504	$ 47,662.00
18	3,5	300	$ 49,892.70
19	3	120	$ 23,249.20
20	4,5	564	$ 51,055.90
21	4	384	$ 24,412.60
22	5	180	$ 26,643.30

This dominance curve created from the data indicates that the optimal decision policy given by DPL™ (Strategy 10) is on the frontier curve. The curve show that other project selection strategies also fall on this line and can be selected depending on the decision makers values and willingness to trade off one criteria for another. (Strategies that fall on the dominance curve are shown in bold lettering.) The dominance curve is shown in Figure 4-12.
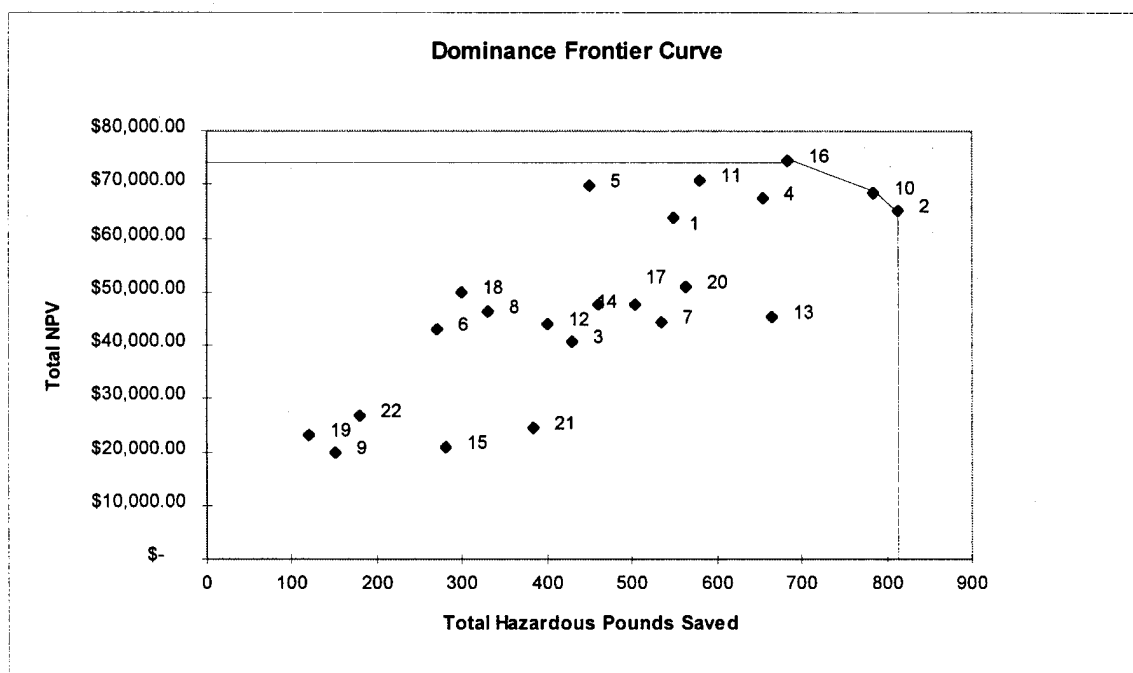

Figure 4-12. Dominance Curve

What is interesting to point out is that the optimal decision strategy given when there were no uncertainties was strategy 10. The chosen strategy when uncertainties were added is to select projects 3,4 and 5 which is shown here as strategy 16. Both of these strategies lie on the curve indicating that DPL™ will not select a strategy that is not on

the dominance curve. This can be further shown by comparing the dominance curve to

Figure 4-9 which is the rainbow diagram for the economic weight. Figure 4-9 indicates

that the decision policy changes three times with regard to the economic weight. The

dominance curve also suggests that there are three optimal policies depending on the

tradeoff value of the decision maker. Running the model with an economic weight of 0.5

it has already been shown that strategy 10 is the preferred alternative. The optimal

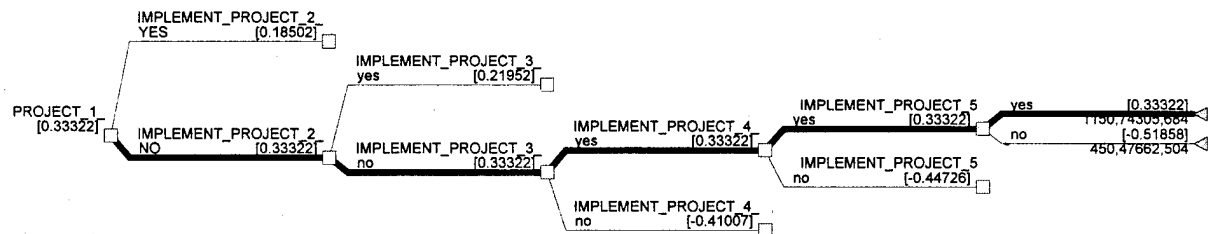decision strategy with an economic weight of 1 is shown in Figure 4-13.

Figure 4-13. Optimal Decision Policy 2

As predicted the optimal policy is to select projects 3,4 and 5 for implementation

(Strategy 16). Running the model with an economic weight of zero will give an optimal

decision policy of selecting projects 1,2 and 4, which the dominance curve shows as

strategy 2. This is shown in Figure 4-14.

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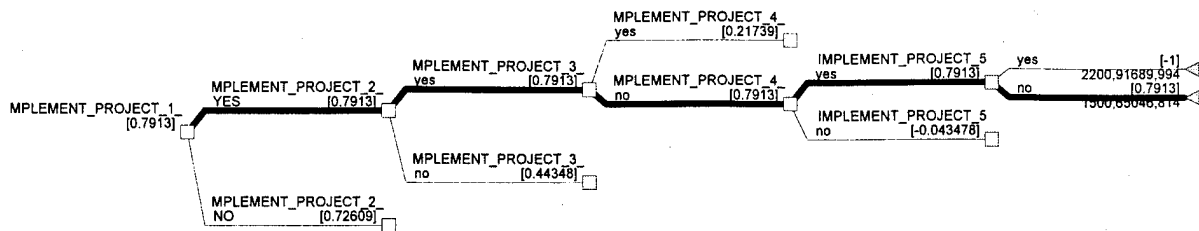
Figure 4-14. Optimal Decision Policy 3

The only three strategies selected all fall on the dominance curve. Dominance will keep strategies that do not lie on the curve from being chosen (as shown when uncertainties were added to the model.) Dominance Curve Analysis allows the decision maker to see which strategies are optimal depending on the tradeoff values. For instance if there was an immediate objective change at the decision maker's installation to reduce the highest volume of waste possible, it is obvious from the dominance curve that Strategy 2 should be chosen over the strategy chosen with an economic weight of 0.5 (Strategy 10).

Summary

For decision makers to use this model, objective and subjective inputs must be entered. Objective inputs are based on values received from a contractor after an Opportunity Assessment is performed. Subjective inputs are based on the decision maker's values and knowledge of the pollution prevention projects in question.

Once values are entered into the model, Decision Analysis is performed to determine the optimal decision policy based on the values. The next step is to perform Value Sensitivity Comparison (the tornado diagram) to determine which values are the most critical to this optimal decision policy. The values determined to be critical are then analyzed using Value Sensitivity Analysis (the rainbow diagram). These diagrams and the decision maker's confidence in the values will determine if uncertainty nodes should be added to the model. If so the model is run again to determine if the optimal decision policy changes.

Another method to determine the optimal strategies is to use the values from the Decision Analysis to create a Dominance Curve. This curve will indicate which strategies lie on the curve and dominate other strategies. This curve will indicate to the decision maker the optimal strategy for project selection based on tradeoffs of the two attributes used to compare the strategies.

Using the two methods together allows for justification of the strategy chosen for implementation. Having one method to confirm results from another method will make it easier for the decision maker to stand behind the decision of which projects to implement.

V. Conclusions and Recommendations

Conclusions

The analysis of the case study demonstrated a systematic method for selecting the optimal group of pollution prevention projects to implement. This model provides the decision maker with an analytical justification for the strategy chosen. This is helpful during times of declining budgets when pollution prevention managers must often prove to the Installation Commander that the projects selected will give the most environmental benefits for the dollars spent. The model allows for two methods of justification to ascertain that the decision was the correct one for the objectives of the installation.

Decision analysis theory provides an excellent framework for selecting the optimal mix of pollution prevention projects. This method allows for uncertainty which is critical in the environmental arena where new technologies are emerging daily. Sensitivity Analysis provides crucial insight to how critical a certain value is to the model. Performing this analysis would be extremely complicated to the decision maker without the aid of this model. With sensitivity analysis the decision maker can vary inputs to accommodate any scenario that the decision maker might deem possible. The Dominance Curve provides a means for the decision maker to recognize all possible strategies for the selection of pollution prevention projects. Depending on the objectives of the installation at the time, the decision maker can determine which strategy would be the most beneficial by where the strategy lies on the curve.

Running decision analysis and sensitivity analysis provides the decision maker with a concrete optimal decision policy and the option to examine individual values closely. It does not allow the decision maker to view all possible strategies. The dominance curve provides a forum to show the decision maker all optimal strategies depending on the values of the decision maker, but this method is more time consuming. Since decision analysis and sensitivity analysis are built in functions of DPL™ the results are easily seen. The dominance curve must be constructed from data provided by decision analysis which is more work for the decision maker. Used together, the positive aspects of the methods create an excellent tool for use by the decision makers.

The model will be more useful once research can provide more accurate data on two key value nodes: 1)Dollar per Waste Pound and 2) Hazardous Ranking. Research that HSC began should be continued for more than seventeen chemicals (20). The Hazardous Ranking value node would be more valuable if it did not rely solely on subjective data.

The model will work best on a smaller scale to allow for a shorter run time and a simpler analysis, although theoretically the model will incorporate an unlimited number of projects. Run time for the five projects in the case study was less than 10 seconds. When uncertainties are added run time increases. For the model in the case study the run time was approximately one minute. As the size of the model increases and more uncertainties are added, the decision maker can expect the run time to increase. A way to

accommodate for this would be to use the model on an organizational by organizational basis rather than installation wide.

Compliance driven projects will have top priority when selecting projects and thus will typically not be a choice for a decision maker. The model is an excellent tool for the decision maker for selecting projects from once the required projects (P1) are removed from the recommended alternatives. If there are not enough resources to implement all of the required projects, then the model can also be used to aid the decision maker in selecting between P1 projects. The use of this model does depend on reliable and accurate data. Therefore the decision maker should request the data for the model nodes from the contractor who completes the installation's Opportunity Assessment. If the OA is performed by base-level personnel, instructions should be given on how to determine the required criteria.

Recommendations for Further Research

This model could be improved by further researching the values of the base-level pollution prevention managers. With more inputs from the field, importance of criteria could change or be deemed more or less important than criteria used. It would be beneficial to perform more research for the Hazard Ranking value used. A more objective input would provide a more reliable result. Research might show that hazardness could be broken down into ecological and health effects thereby using risk assessment methods to provide input. It might also be possible to create a hazard index

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which merely lists hazards in a relative ranking. This research would be very useful to the model in the present form.

The decision analysis principles used in this case study could easily be applied to fields other than the environmental arena. For instance the model could be incorporated to select among construction project, but research would be needed to determine important criteria, required weighting scales, and the objectives of the decision maker. The framework is created, all that would need to be changed is the criteria used for selection.

Appendix A

This appendix contains a compilation of responses received from the questionnaire sent to base-level pollution prevention managers. Thirty three percent of the questionnaires sent out were returned. For non-attribution reasons, any references to the person responding or their installation was deleted, otherwise responses are typed exactly as shown on the completed questionnaire. The question asked is in bold followed by the numbered responses of the managers surveyed. If a manager did not respond to a certain question then the number corresponding to that manager was left out completely.

When selecting pollution prevention projects to implement, is your choice based solely on payback period?

1. No

2. In some cases, no. Recycling is the most prevalent case that comes to mind. Recycling cures a lot of ails, yet "payback" may never be attained.

3. No

4. No

5. No

6. No, Payback period is a means of selling the project to senior staff, but the "bottom line" is what waste streams are we trying to eliminate and what impact do these waste streams have on the installation and the environment.

7. No

8. No

9. No

10. No

11. No

12. No

13. No

14. No

15. No

16. No

17. No

18. No

19. No

20. No

If not, what other factors do you consider?

1. Anticipated or existing compliance with regulations or policies are also driving factors. Pollution prevention is costly and to solely base implementation on payback can severely limit meeting requirements.

2. Doing what is "environmentally smart".

3. Equipment performance, contractor performance, manpower requirements, feasibility

4. Cost of project, needs of customers

5. Benefits to the environment such as hazardous waste reduction

6. Elimination of waste streams, liability, manpower requirements, funding, compliance.

7. I consider these addition factors - IMPACTS on: hazardous waste and solid waste generation; water quality and EPA 17/ODC reduction goals.

8. I do a cost/benefit analysis; will the project make a process more efficient? I also give the project the common sense test; Is the project feasible, even with a short payback period; and how easy it will be to implement and maintain after purchase.

9. Desire of the shop/organization to use/implement is very important. Some people won't change so we go firsts with those that will.

10. The needs of different squadrons--where more waste will be recycled. e.g. antifreeze recycler instead of stencil machine.

11. How much will it reduce a Hazardous Waste stream is my most important factor,

12. Total quantity of waste to be reduced, hazards associated with the waste

13. Environmental impact such as amount of waste or emissions reduced.

14. Desire of customer to implement change, feasibility of actually implementing the project, consider economics from standpoint of one large project versus several small projects, total picture, reduction in pollution with money available

15. What will give me the greatest hazardous waste, solid waste, or hazardous material generation reduction; where we sit at the present time in reaching our goals in reduction; is it a level P1,P2 or P3 project.

16. Value of the project in meeting environmental priorities

17. Safety, health, environmental benefits, reduced risks, public response

18. Is project legal under AFI 32-7080?; Does project eliminate ODC's or EPA-17's?; Will I get funding?; Can we reduce hazardous waste stream or solid waste stream?

19. Volume or amount of pollution prevented; efficiency of new process versus the old process; compliance with existing or future regulations.

20. Process change: Will the project eliminate use of an EPA 17 toxic? Minimize hazardous waste production or minimize solid waste? Also: availability of the unit to operate equipment or work with process change: How well accepted will the change be?

If yes, why do you not consider other factors?

Do you feel the payback period is an adequate measure for choosing the best pollution prevention projects?

1. No, not in itself

2. No

3. No, but it is mandated

4. No

5. No

6. No

7. No

8. No

9. It is adequate mainly for technical review. In the real world you must also meet commander and HQ desires.

10. Overall yes

11. No

12. From an economic standpoint, yes. From an environmental standpoint, not necessarily.

13. No

14. No

15. Payback period is only one consideration

16. No

17. No

18. No

19. It is adequate if it can be done with accuracy. This is not always the case.

20. No.

Please state why or why not.
1. Cost payback should be a factor but not the sole factor

2. As a base competing against others for funds, unless I can show payback I will not get the funding.

4. Not all projects have a payback

5. It needs to be a part of the decision process. However, many of our pollution prevention initiatives would ever happen if they were only measures of payback period.

6. Payback period is only one aspect of a P2 project in some instances it might not even be a consideration due to a change in the law which requires compliance regardless of cost. If we are

truly complying with the intent of existing federal and state environmental laws payback period can not be the only measure.

7. Payback period is not good as a sole factor in determining what projects to select because, too often, process changes needed to meet goals don't necessarily lend themselves to quick or tangible payback periods, e.g. base-wide recycling, which reduces solid waste generation, does not have a tangible payback for a reserve base.

8. A project can have a 1 month payback period, but still might not be feasible, consider the ease of execution of a project! The project must also be necessary and meet P2 criteria.

9. Simple payback does not always peak the interest of users and managers. You have to be a good salesman!

10. It helps when it comes to wise spending of your P2 money,

11. A measure may actually cost money, but , if it reduces or eliminates a hazardous waste stream it is still a valid measure.

12. We certainly cannot ignore economics when making critical decisions on how to invest our resources. However, we often fail to consider the entire picture when calculating payback period. For example, when we consider the use of solar energy to reduce our demand for fossil fuels, solar technology is almost always more expensive. The use of petroleum has hidden costs, however, which must be considered; costs such as remediation of petroleum spills. Another drawback to using economic payback is it fails to consider intangible benefits to human health and the environment such as improved air quality, decreased exposure to toxic substances, etc.

13. It has a built in bias for inferior quality. Internal rate of return is a better form of economic analysis. But economics alone do not tell the whole story. Environmental impact and safety considerations are vital parts of the equation.

14. Because some projects may reduce EPA 17 for example but have little or no payback.

15. It is only one parameter

16. Sometimes the payback period may be longer but the ultimate gain in reducing pollution is better than projects with short payback periods. Also, some projects may not be done with a shorter payback period regardless of funding availability due to the engineering involved.

17. Pollution prevention has many intangible benefits that must be used to help make a decision. The most cost effective project may not be the best project.

18. Often times pollution prevention projects have no defined payback. For example, here in the Northeast, recycling is a losing ($$) proposition. However, a strong recycling program provides good PR with the local community and state.

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19. It is adequate to give you a quick check to see if you have a good project or whether you will be wasting lots of time and money with little benefit.

20. As stated above, users are the ones who will live with the PP changes. If they are not willing to operate a solvent distiller then we need to come up with a different alternative regardless of the payback period.

Do you feel that using another method besides payback period would result in significant changes in pollution prevention projects chosen?

1. Yes. It would open up other project opportunities normally eliminated because of long payback. Would give bases more flexibility in tackling base concerns.

2. Yes.

3. Yes

4. Yes

5. Yes

6. Not at this time since payback period isn't our only measure

7. Yes

8. Not significant changes, but would enable managers to look further into the future effectiveness of a projects, beyond the payback period.

9. Other logical, though out processes will get similar choices, but sometimes logic does not come into play!

10. Not significantly

11. Yes

12. Probably not. Most P2 projects with high payback periods tend to enhance protection of human health and the environment.

13. Hard to say. Based on my observations, payback has relatively little to do with what gets funded. IT depends more on the ability of the program manager to advocate for resources form HQ, the speed with which funds can be obligated, and the degree to which the project can be tied to some pet project of HQ (e.g. Hazmarts) or some political hotbutton (e.g. ODCs).

14. Yes--in some cases.

15. Payback is not the only consideration

16. Yes

17. No single method should be used. All issues should be addressed

18. Not under the present system HQ uses.

19. Yes

20. No. Currently at base level projects are chosen based on EPA 17 or waste minimization opportunities and on Tech Orders--driven requirements
What other factors would you like to see used to select projects?
1. Quantity, quantity/unit cost, and risk associated with all P2 programs. (e.g. large volume chemical reductions, health concerns, etc.)

2. Place more emphasis on environmental benefits; pollution prevention, energy conservation, waste reduction...in other words getting back to the basics. We've spent a lot of money getting into the environmental mess we are in so we must spend money to get us back on track.

3. Performance, waste minimization, pollution reduction

4. Customer needs, and percent of waste reduction

5. Waste reduction, worker safety

7. IMPACT measurement on waste generation, water quality, air quality and environmental goals.

8. Time-Life span of a project, user friendliness, idiot proof or easy to maintain, ease of purchase and implementation, Is the project a significant benefit to an organization and the Air Force?

9. Work efficiency improvement

10. You just have to know what will benefit the base the most--Amount of waste diverted.

11. Hazardous Waste reduction

12. Ability of project to help base meet AF goals. A project which may drastically reduce hazardous waste generation (therefore help us meet 50% reduction goal) may not have a high payback period.

13. Environmental impact and safety considerations.

14. Consider pollution reduction percent versus money saved.

16. Long term gains in P2 versus short-term smaller gains; spending more up front on P2 to eliminate the source rather than spend a lesser amount on compliance.

18. Elimination of TRI chemical purchases, reduction of hazardous waste or solid waste streams.

19. The factors I listed above.

20. Deletion of EPA 17 requirement

Does your budget limit the number of projects that you implement in a given year?

1. Qualified yes. Essentially the limiting factor is what Headquarters is willing to fund.

2. Definitely. For example I asked for $1.6 million for FY 96 and I am receiving $294K. Talk about limits.

3. Yes

4. Yes

5. Yes

6. Not significantly, but it would depend on requirements by the other environmental programs.

7. Of course my budget is limits the number of projects I implement in a year - that is why the projects are prioritized.

8. Yes, big projects (>$100,000) are almost never funded, even if they are justified.

9. No, our PP budget is very healthy at this time.

10. Yes

11. Yes

12. DEFINITELY. Even projects with short payback periods are frequently not funded due to budget constraints.

13. Somewhat

14. We do not receive a budget. Projects are approved by MAJCOM on a case by case basis. They give specific amounts for specific projects.

15. HQ funds projects, but their budgets limit the number of projects we implement.

16. Yes

17. Yes, the wish list is always much larger than the pocketbook.

18. My budget always limits the number of projects I do each year. We try our best to "think of" projects that fall within the rules set by our HQ, but are not always successful in getting everything funded.

19. Yes

20. Yes, out of 990K programmed only got funding for 754K for FY95.

If you were to choose projects based on environmental benefits do you (would you) consider mainly human or ecological effects of the waste eliminated?

1. That is a loaded question. We have to do both

2. My first thoughts are to do what is ecologically safe and since humans are a part of that ecology they would only benefit.

3. Both

4. Both factors should be considered

5. Human effects

6. Ecological would probably be the primary but it depends on the type of waste stream. Consider the fact that ecological in the long term factors in human consideration. The only exception to this would be if I could eliminate a particularly hazardous process that was a clear and present danger to humans.

7. When choosing P2 projects, both human and ecological effects of the wastestream eliminated are considered equally. If these are the only factors remaining to decide between two projects, then impacts on human effects would have a higher priority.

8. You have to consider both, but when it comes right down to it I am worried about human effects first.

9. Human first, ecology second, but both are important--but people come first!

10. Human

11. Human

12. I would consider both (probably equally)

13. Human and ecological factors are inextricably linked. However, I would put more weight on those projects which had the most direct benefit on humans.

14. No. I would consider the P2 goals like reduction of EPA 17 or hazardous waste generated and the possibility of reducing those.

15. A combination of both

16. I would consider both equally. Whatever affects the ecology will ultimately affect humans.

17., I wouldn't lean one way or another. All projects should be weighed on their own merits with proper attention given to all effected areas.

18. Ecological (there are others who consider the human effects)

19. No

20. Either: waste eliminated will not go to an incinerator/landfill which harm both humans and earth.

Is manpower a major consideration when choosing projects?

1. No

2. No

3. Yes

4. No

5. Yes

6. Yes

7. No

8. Yes

9. Yes, many times we don't have time to evaluate projects well, we go with "gut feeling" more than hard numbers.

10. Yes

11. Yes

12. Yes

13. Yes

14. No, but it is a factor.

15. Yes

16. No

17. Yes

18. Yes

19. No

20. Yes

Please state why or why not.

1. Most projects are done by contract. The shear number of projects to be manages could be limiting factor since base personnel normally are the OPR for the project for their individual organization.

2. I attempt to do all in my power to choose projects necessary for the base. I will pull the entire
base populace to get the project complete.

3. In order to get the project done effectively, you must have trained, knowledgeable, dedicated and committed people to do it.

4. Each project must be weighed separately--other factors must be considered.

5. Many of these projects require a significant amount of manpower to implement.

6. We are manned mostly by civilian employees. Any P2 project that would require an increase in man hours would require the hiring of another position is a significant problem.

7. Most projects involve process changes. Any chosen solution to process change must have minimal impact on manpower. The only exception I have come across pertains to recycling solid wastes - lack of manpower results in contracted services.

8. The P2 shop is basically tow people and P2 is a broad scope job, it is very difficult to incorporate all aspects into projects funding with limited manpower.

9. Pressure to get things bought now so we don't lose the money!

10. We have only one person doing P2 half of the time.

11. Manpower is very limited and I can't pick a project that would make things worse.

12. Some projects require intense investigation prior to being implemented. IT can be difficult to find the time to adequately investigate P2 projects which may significantly reduce waste generation.

13. When manpower ceilings are in effect you cannot undertake a project that requires extensive manpower no matter how much money it saves or how much money you have to spend on the project, or how much it will benefit the environment.

14. You need personnel to conduct OA's and to deal with the MAJCOM programmers.

15. If you are buying a new piece of equipment - consideration has to be given to installation and operating of the equipment.

16. This office handles mainly funding and the contract actions. As a management organization we are staffed to handle this type of work. If this organization actually performed the research, then manpower would be a limiting constraint. If funding weren't a constraint, then we probably wouldn't limit the number of projects undertaken in a given year.

17. You shouldn't bite off more than you can chew. IT is very unwise to solicit funding for something you can't implement.

18. IF I had more "bodies" my office could manage more projects in greater detail. No one wants to give up bodies for PP. As it stands right now about 1/5 of my non-facility repair FY95 budget is tied up in contract employees.

19. Manpower is a major consideration when prioritizing projects, but not for choosing projects

20. If a shop has no time/person/training to operate a recycler/distiller etc. they will just drum up the wastes and let the recycler sit unused.

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13. ABSTRACT (Maximum 200 words)

Pollution prevention managers need to select the best environmental projects for an installation within a constrained budget but have no standard way of selecting the optimal mix of projects. This thesis proposes a decision tool to aid decision makers in choosing this optimal mix. The model was built using decision analysis theory which provides a framework to aid the decision maker. Criteria used in the model for selection was determined using a questionnaire sent to base-level pollution prevention managers. The model uses DPL^{TM}, a software package designed to build, analyze, and conduct sensitivity analysis of decision problems to perform the quantitative analysis. Built in functions of DPL^{TM} allow the decision maker to see the optimal decision policy based on the values entered into the model and to run sensitivity analysis to determine which values are the most critical to the outcome of the model. Decision analysis can be used to create a dominance curve that shows all optimal strategies based on the willingness of the decision maker to make tradeoffs between attributes. This model provides analytical data that can be used to justify decisions made by the pollution prevention manager when selecting the optimal mix of pollution prevention projects for implementation.

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